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Wastewater Sampling Transfer and Conditioning System

Raytheon Co, Portsmouth, R I Submarine Signal Div

Prepared for

Municipal Environmental Research Lab, Cincinnati, Ohio

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16. ABSTRACT

This report describes the construction and field evaluation of an automatic on-line hardware system for reliably sampling, transferring, and conditioning various wastewater-treatment process streams such that the resulting transferred and conditioned samples are suitable for interfacing with automatic on-line colorimetric and total organic carbon analyzers. Process streams to which this hardware system was sucessfully applied included raw sewage, primary effluent, secondary effluent, aeration tank mixed liquor, and return activated sludge. Primary sludge could not be sampled at the field-testing site because the sludge had become too thick at its only feasible access point. Analytical parameters used to evaluate the hardware system included both total and soluble organic carbon, orthophosphate, total hydrolyzable phosphate, and ammonia nitrogen. Nitrate and nitrite were not included; however, the hardware system's performarce with the soluble parameters studied indicate that nitrate and nitrite should present no special difficulties.

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WASTEWATER SAMPLING, TRANSFER AND CONDITIONING SYSTEM

by

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DISCLAIMER

This report has been reviewed by the Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural enviroment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

To help implement the above, this study describes development of an automatic on-line sampling, transfer and conditioning system for monitoring wastewater-treatment process streams.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

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The preliminary investigations, as well as all system designing, construction, and testing, were performed with the invaluable assistance of H. Duane Evans.

SECTION I

INTRODUCTION

The purpose of this project was to develop automatic, on-line equipment for sampling, transferring and conditioning wastewater-treatment process streams for automated analyses for total and soluble organic carbon, ortho- and total hydrolyzable phosphate, ammonia, nitrate, and nitrite. Furthermore, these sampling, transferring and conditioning steps were to be accomplished without causing unacceptable chemical changes in the sample prior to any of the analyses. Ultimately, automated sample-handling equipment of this type will be a necessary component of completely automated, wastewater-treatment processes and plants.

The major factors requiring consideration were: a) the necessity of limiting the size of suspended solids particles in samples that could not be filtered prior to analysis, b) fabrication of a suitable automatic manifolding and switching network, c) assurance that all samples would be representative of the process streams from which they were taken, and d) total system reliability. A brief discussion of each of these factors follows.

Limiting the Size of Suspended Solids Particles

The suspended solids and refractory matter present in wastewater prevent the use of typical off-the-shelf colorimetric or organic carbon analyzers without sample pretreatment.

The total organic carbon (TOC) analyzers presently used in most wastewater-treatment laboratories accept samples of 50 microliters, or less. These relatively small volumes are required by the small injector assemblies and combustion reactors incorporated in such laboratory analyzers. In addition, multiple injections of a well-homogenized sample are required for obtaining reliable data. Regardless of TOC-analyzer design, however, incoming samples must meet suspended solids limitations not only on average particle size, but also on particle-size range; otherwise, not only would the analyzer tend to clog, but the analyzer's data would contain intermittent and unpredictable outliers or data "spikes" that could ruin much of the total output.

Colorimetric analyzers provide false data when high suspended solids concentrations are present in the sample streams. Large particles tend to clog the colorimeter's automatic delivery system, while small particles limit light transmission. Finely suspended material causes backscatter (Tyndall effect), and this also creates artificially high absorbance values. Thus, in either case the true value is masked.

Accurate data can be obtained only through proper conditioning (i.e., homogenization or filtration) of the sample before the sample enters the analyzer.

Automatic Manifolding and Switching

The extended retention time of a typical wastewater-treatment process dampens the short-term changes in most measured variables. This permits analytical time sharing whereby a single analyzer can be used to monitor several process streams without significant loss of data; although occasionally, full-time monitoring of a process variable may be necessary.

The optimum situation is to supply a continuous flow of several different types of samples to a centrally located, valved manifold. At this location, the sampling sequence, sampling time and sample conditioning would be controlled by an automatic switching device, with a manual override for experimental work.

A centralized monitoring system offers the following benefits:

1. fewer analyzers to purchase,
2. fewer analyzers to maintain,
3. reduced chemical consumption,
4. easier surveillance,
5. easier isolation from the hostile environment of a wastewater-treatment plant.

Centralization, however, often requires long transfer distances which can cause unreliable data. Therefore, proper sizing of transfer lines to obtain optimal flow must be taken into consideration.

Assuring Representative Samples

Of primary importance in any sampling and conditioning system is whether or not the sample taken is representative of its source, and whether the sample has undergone a chemical change as a result of the conditioning process. This factor is dealt with by proper sampling, sample transfer (i.e., transport), and sample homogenization or filtration.

Reliability

Most automatic sample transfer and conditioning systems have been so poorly designed and/or mechanically unreliable that the chemical integrity of the transported sample has received little or no attention. To be successful, an automatic sampling system must utilize essentially troublefree hardware that has been thoughtfully integrated into a highly reliable system capable of continuous unattended operation.

With these facts in mind, Raytheon designed and constructed an automatic, on-line, wastewater-sample transfer and conditioning system to make automated process stream analysis and process control possible, and thus fulfill a need which is daily becoming more urgent.

Test Location

The Water Pollution Control Facility for the City of Cranston, Rhode Island, was chosen as the test facility for this program. The facility utilizes an activated sludge process and has a daily flow of 6.84 million gallons (26,500 cu m). The plant's size and population it serves (75,000 persons) make it a typical operation. The proximity of the plant to Raytheon's facility, as well as the good working relationship between Raytheon and the City of Cranston through the years, were additional factors that influenced the decision to conduct the study at that particular location.

Although the Cranston facility has adequate laboratory and office space to accommodate the project's requirements, piping the sample transfer lines to the central laboratory would have been most awkward. Also, such an arrangement would have created a safety hazard for plant operators and maintenance men since the piping would be crossing heavily traveled areas. Instead, a Raytheon owned, environmentally controlled (heated and air conditioned) instrument trailer was set up at the Cranston facility to house the system to be tested.

This program, which extended over a 15-month period, was carried out in two phases. Descriptions of both are reported herein:

Phase I - Preliminary Investigation and Qualification of Components

Phase II- Design, Implementation, Testing, and Evaluation of the Final Sampling System

SECTION II

SUMMARY

This report describes the construction and field evaluation of an automatic on-line hardware system for reliably sampling, transferring, and conditioning various wastewater-treatment process streams such that the resulting transferred and conditioned samples are suitable for interfacing with automatic on-line colorimetric and total organic carbon analyzers. Process streams to which this hardware system was successfully applied included raw sewage, primary effluent, secondary effluent, aeration tank mixed liquor, and return activated sludge. Primary sludge could not be sampled at the field-testing site because the sludge had become too thick at its only feasible access point. Analytical parameters used to evaluate the hardware system included both total and soluble organic carbon, orthophosphate, total hydrolyzable phosphate, and ammonia nitrogen. Nitrate and nitrite were not included, however, the hardware system's performance with the soluble parameters studied indicate that nitrate and nitrite should present no special difficulties.

SECTION III

CONCLUSIONS

General

The sample transfer and conditioning program described in this report has demonstrated that various streams within a typical municipal wastewater-treatment plant can be monitored remotely and reliably for TOC, SOC, o-PO_4, hydrolyzable PO_4, NH_3-N, and NO_3/NO_2-N.

- Sampling, transferring and conditioning was accomplished reliably and continuously without affecting the representative nature of the sample except for particle size distribution.

- Comparison of wastewater sources and interface sample discharge concentrations, as measured by reference laboratory procedures, demonstrated very satisfactory agreement.

- The agreement in reference laboratory TOC values for source and interface proves that sampling of streams containing particulate matter need not be a problem if the following simple rules are followed in designing the system:

  1. Fluid velocities at, or greater than, 2 ft/sec should be maintained in the sample-transport lines.

  2. A sampling manifold that keeps all sample streams flowing continually must be provided.

  3. For the automatic modes, a sampling sequence must be established for sampling the cleanest stream first, then sampling progressively dirtier streams. At the end of each such sequence of samples, a complete flushing of the system with clean water must be carried out.

  4. All fittings, pipes and other wetted components in the sample-transport and manifold systems must be designed to eliminate restrictions and dead zones wherever possible.

- Sample dilution is a viable approach and, if implemented correctly, offers the following benefits: a) multi-stream monitoring, using a single transfer system for high solids and low solids sources, b) minimization of transfer-line contamination by diluting at the source, rather than at the interface, and c) quick multi-stream switching with relatively short purge time (this is feasible because proper dilution minimized the transfer system's solids loading).

- The sample transport and conditioning system provides satisfactory continuous sampling of a single process source; therefore, if satisfactory automated analyzers were to be dedicated to only one process source, continuous on-line remote analyses for that source would be furnished. For multiple-source operation as developed in this study, the on-line colorimetric analyzers restricted the sampling frequency to one process source per hour. The time for transport and conditioning of each sample, however, was only 17 minutes which would have permitted analyses of approximatley three different process sources per hour if sufficient colorimetric analyzers had been added and suitably employed.

- In any interfacing of a sampling manifold with an automatic analyzer, transfer velocities and/or distances within the laboratory space are just as important as are those used to deliver the samples to the laboratory. All automatic analyzers should be as close to the sampling manifold as possible, especially if the sample to be analyzed contains suspended material.

- Where it is not possible to attain optimum analyzer location, analyzer input velocities should be increased to insure that a representative sample is actually being supplied to the analyzers within minimum transport time. This requirement means increase of sample delivery rates to the analyzers, either by changing the sample pump (or pump speed), reducing the diameter of the sample lines, or inserting an additional sample pump to obtain, in each case, a resultant increase in velocity.

- The interface results for most of the automated on-line analyzers tested did not satisfactorily agree with the interface results from reference laboratory methods; the one satisfactory on-line analyzer was that for orthophosphorus. Further development of reliable automatic on-line analyzers is necessary.

SECTION IV

RECOMMENDATIONS

With the initial phases of this program accomplished successfully, there are several areas inviting further investigation:

- How would the costs of completely automated sampling compare with corresponding costs for existing manual sampling techniques?
- Would data reliability be improved by eliminating all human influences and human biases from the sample-collecting operation?
- If preceded by a reliable automated sampling system, could on-line analyzers operate continuously for extended periods without failure?
- Would the availability of real-time analytical data influence plant operation in such a way as to improve effluent quality significantly? Could it likewise be used to decrease plant operating cost significantly?
- Could the concept of "quality assurance" be realized by improving data reliability via appropriate combinations of automatic sampling and automatic analyses?
- What would be the magnitude of improved reliability resulting from the substitution of a three-way motor-driven valve for each pair of two-way valves?
- What effect would changes in arrangement of the analyzers (i.e., relative to the ST & C system's homogenizer and filtration system) have on the consistency of the data, and what (if any) limitations are there in making such rearrangements?

Plant Expansions and New Plant Installation

In modifying and expanding existing plants, and for plants to be built in the future, installation of a permanent automatic sampling system would seem to be the more viable approach. It is quite likely that in the planning stages of these facilities, much thought would be given to the centralization of

sample streams for future monitoring purposes and, ultimately, for automatic process control. Tapping into lines would be no major problem because a new plant could provide for readily accessible sampling ports; however, flow regulation would require some design effort. The flow rates within a large plant are quite high (thousands of gallons per minute), whereas the Raytheon Sample Transfer and Conditioning System requires only 5-6 gallons per minute (19.4 - 23.3 l/min). Careful design of the entire sampling system would be required to achieve a representative sample. In addition, to make the homogenizer function properly and to reduce the likelihood of plugging within the sampling system, the sample would have to be pre-conditioned to reduce occasional large particles to no more than 1/4-inch (6-mm) diameter. An in-line grinder pump, rather than the drop-in type used for this project, would be more suitable for such an application.

The concepts have now been proven; with judicious effort, the problem areas stated above do not appear to present any insurmountable obstacles.

Raytheon recommends that further wastewater transfer and conditioning studies be performed to answer these questions.

Portable Installations at Existing Plants

An effective sampling strategy must be adaptable to existing plants, as well as to those constructed or modified in the future. A single sampling system, adaptable to both, may be unnecessarily flexible and expensive. The most practical solution to this problem would be to design a mobile system for investigating existing plants. With the type of equipment developed during this program, an investigator could go into a treatment plant with a trailer, housing the sampling manifold and a battery of automatic analyzers, and within a very short time, he should be able to assess the plant's efficiency and initiate steps to rectify problem areas. Being portable, such an analyzer system would require no major on-site construction. The mobile facility might be owned by the EPA and leased to municipalities as required. This is the most practical approach for existing plants since their piping is not readily accessible. Such an approach would allow rational investigation of the possible cost benefits of a permanent sampling system; it could also be coupled with existing automated plant controls without excessive capital outlays. In either case, such a portable system could help answer many of the questions posed in the foregoing part of this Section.

SECTION V

PRELIMINARY INVESTIGATION AND ACCEPTANCE TESTING OF COMPONENTS

The sample transfer and conditioning system was fabricated from a number of components. These components were a sample transfer pump, a homogenizer, a filter, and a sampling manifold. A discussion of the selection and design criteria for each of the critical components is given below.

Sample Transfer Pump

There is great diversity in the physical makeup of wastewater-treatment streams. A pump must be able to handle clean streams, as well as streams that contain high amounts of foreign material--plastics, paper, fibers, and wood chips. Such foreign material provides a formidable deterrent to continuous pump operation. Raytheon has utilized the Hydr-O-Grind pump manufactured by the Hydromatic Pump Company in previously developed systems, and has found it perfectly suited to sample raw influent, primary effluent, and secondary effluent.

The Hydr-O-Grind is a submersible centrifugal pump, possessing a grinder unit mounted on the input; see Figure 1. The pump impeller is manufactured from ductile iron and is cadmium plated. The grinder's stationary and rotary cutters are made of hardened, ground, stainless steel. The pump and grinder are mounted on a stainless steel shaft, supported by ball and sleeve bearings that are oil lubricated. No additional lubrication of the motor or seals is required.

The Hydr-O-Grind's pump can be operated continuously at a regular flow of 1 to 30 gpm (3.79 to 113.54 l/min) against a maximum head of 90 feet (27.43 m). The motor is 1-1/2 horsepower, 3-phase, and 209 to 230 volts. The motor winding, rotor, and bearings are completely sealed in oil that lubricates the bearings and transmits heat from the windings to the outer shell.

The working elements of the grinder pump are a grinder ring and impeller that macerate gross solids and a secondary cutter/impeller that further macerates these solids to a reduced particle size of 1/4 inch (6 mm) for pumping by the centrifugal pump.

The complete front end of the grinder pump (inlet, outer impeller, grinder ring, inner impeller and centrifugal impeller) can be removed without affecting the seals, motor or installation.

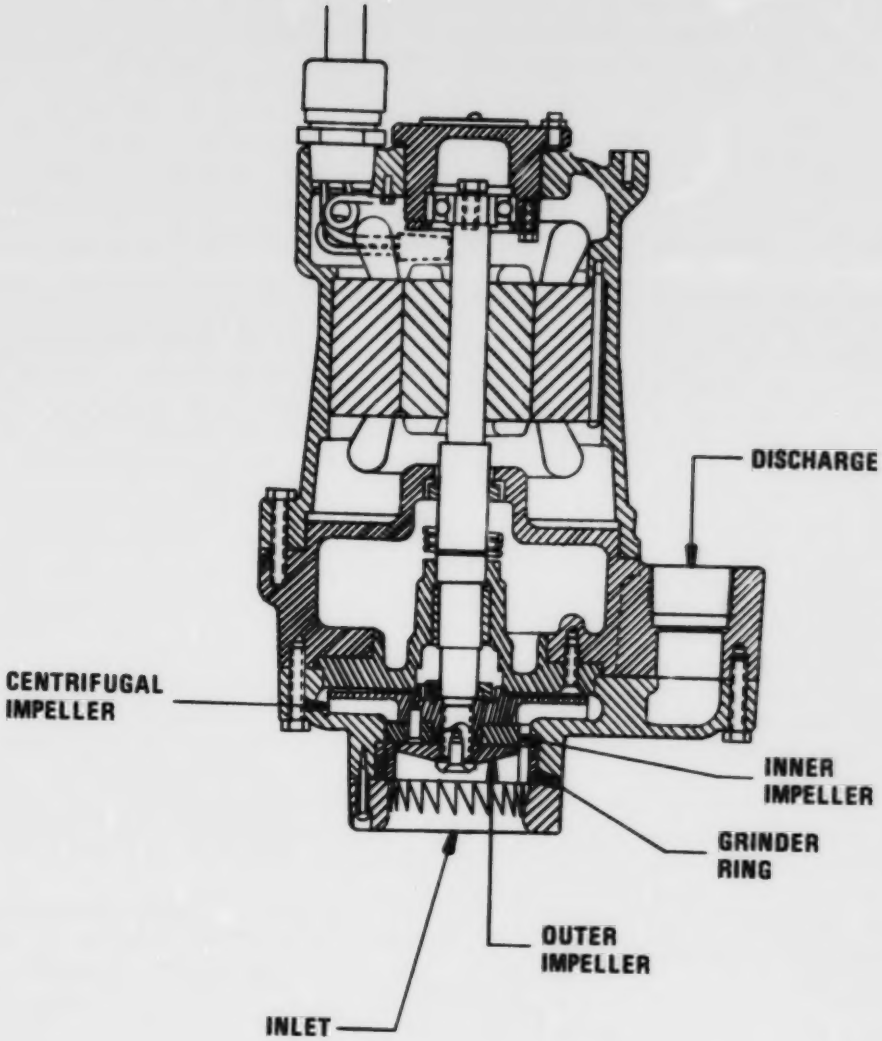


Figure 1. Hydr-O-Grind Pump

Homogenizer

Wastewater streams contain all types of particulate matter (plastics, paper, fibers, wood chips, etc.) as well as domestic sewage. This material must be continuously and reliably reduced to finely divided, uniform, particle sizes in order to be assimilated by any TOC analyzer.

The Raytheon Homogenizer (patent pending), used on transported Hydr-O-Grind effluent, was selected on the basis of its proven capability to fill the above requirement. This homogenizer (Figure 2)consists of the following parts:

- An electric motor — 1 hp, 115V, single phase, 3600 rpm
- Sealed bearings
- A micrometer adjustment wheel to regulate homogenizer-effluent particle size
- A housing manufactured of a material that is impervious to corrosion
- An abrasive stator and rotor

In operation, the sample is pumped at a prescribed flowrate of 3-6 gph (11.36 - 22.71 l/hr) through the inlet of the homogenizer and is then processed between the abrasive stones of the rotor and stator. The design of the rotor-stator abrasive stones permits the reduction of solids to small particles without buildup of homogenized solids on the grinding surfaces; in effect, the abrasive stones are self-cleaning.

Field experience with this type of homogenizer has demonstrated that it is capable of reducing such difficult materials as plastics to a fine particle size on a continuous basis without any buildup on the grinding surfaces, a problem typically associated with solids blenders.

Filter

As mentioned previously, filtering plays an important role in determining the success or failure of colorimetric analyses. This system's pretreatment filtration unit incorporates an automatically controlled backwash sequence that may be initiated by a manual push-button, or by automatic internal sensing elements.

The Raytheon Pretreatment Assembly (Model 2550) utilizes a two-stage filtration process. The first stage is a self-cleaning wash-flow filter which eliminates the large particles. The second-stage filter is a fixed-media bed which reduces the filtrate from the first stage to particles of 12 micrometers, or less.

Component-Testing Manifold

To expedite testing of the filter and other system components, a preliminary

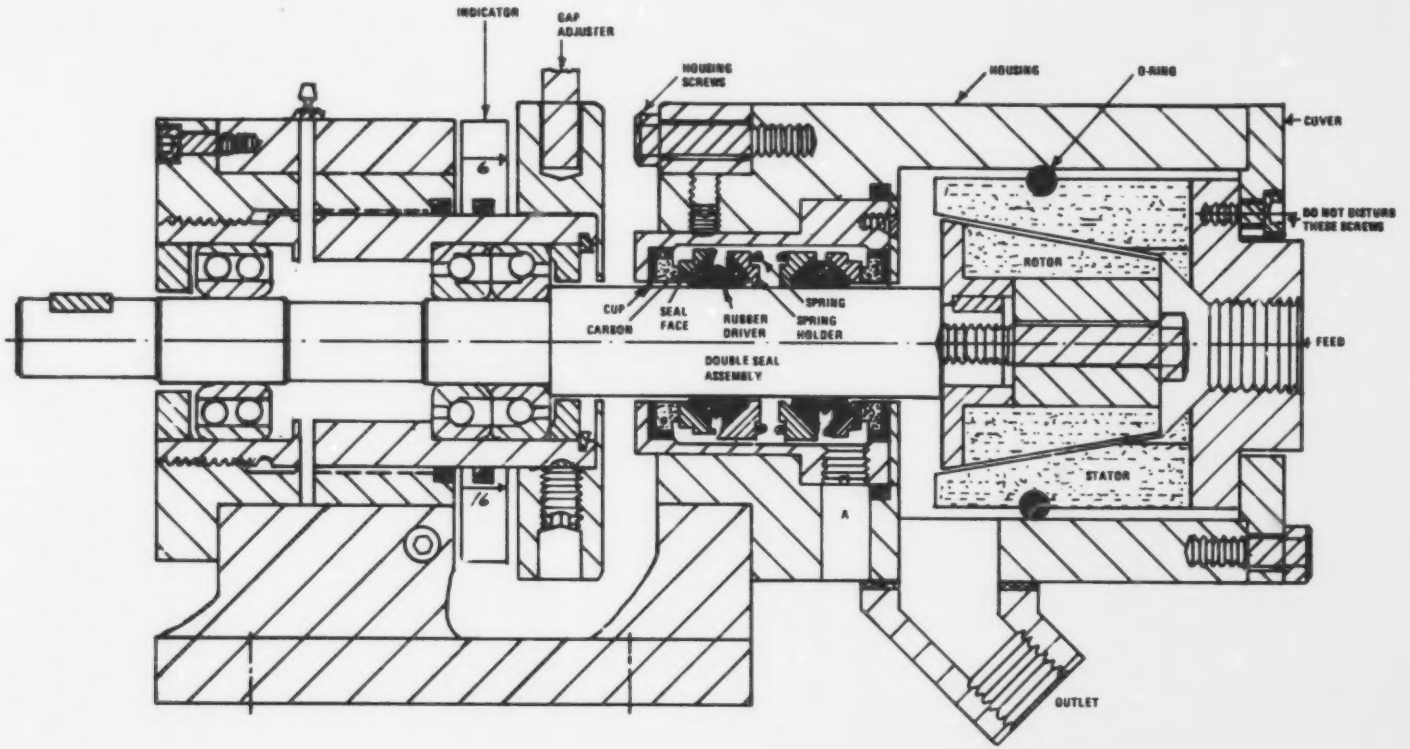


FIGURE 2. RAYTHEON IN-LINE HOMOGENIZER

sampling manifold was constructed. Figure 3 illustrates the flow diagram. The wash-flow filter, the fixed-media bed, and the filter's pump were piped to a test manifold consisting of a series of ball valves capable of directing various samples to the desired locations. Gauges were installed at appropriate locations on the manifold to provide pressure and temperature data which provided additional information to establish effective acceptance criteria for the individual system components. This preliminary manifold served as a valuable investigative tool in the acceptance testing of all system components. Its flexibility enabled Raytheon personnel to test variations in particle-size reduction as a function of sample flowrate merely by changing orifice sizes.

It should be noted that the preliminary manifold was essentially a test vehicle and that the flow diagram shown in Figure 3 in no way reflects the final configuration of the sampling system described later in the "Final System Design" Section.

Test Location

Checkout and testing of the design of the sample transfer and conditioning system were conducted at the Water Pollution Control Facility for Cranston, R.I. A mobile laboratory was located opposite the grease floatation unit as indicated in Figure 4. The location was selected so that unused samples could be exhausted back into the system without affecting the plant operation.

Acceptance Testing of Components

To demonstrate that a representative sample could be taken, transferred, and conditioned without altering the chemical composition of the original sample, appropriate analyses were performed on paired samples. Sets of two grab samples (i.e., sample pairs) were taken: one sample from the stream source and another sample following sample transport and conditioning. Each of these sample pairs was then characterized for particle-size distribution and for TOC value, and the values for each pair of samples were "cross-compared".

First Tests of Particle Size

To determine particle-size reduction by homogenization, four tests were set up, using the following generally-accepted techniques: a) settleable solids measurements, b) suspended solids measurement, c) microscopic examination, and d) sieving.

Settleable solids measurements were made in an attempt to demonstrate that differences in settling rate had a direct relationship to particle-size reduction. This test proved inconclusive.

Suspended solids measurements were also made in an attempt to show that solids content remained unchanged during sample transport and conditioning. A Millipore filter apparatus (Figure 5) was used for this purpose. This test also gave inconclusive results.

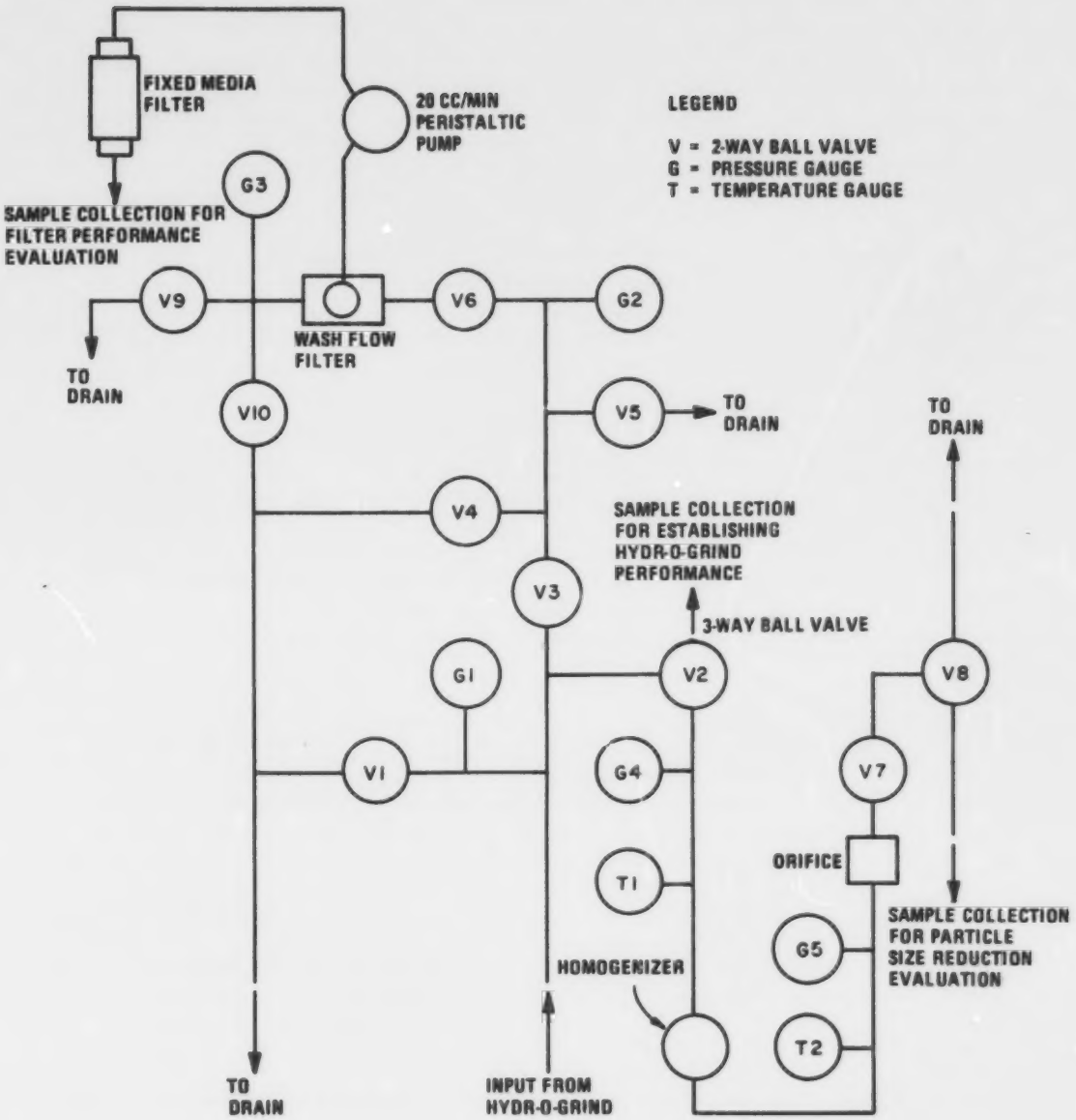


FIGURE 3. PRELIMINARY SAMPLING MANIFOLD FLOW DIAGRAM

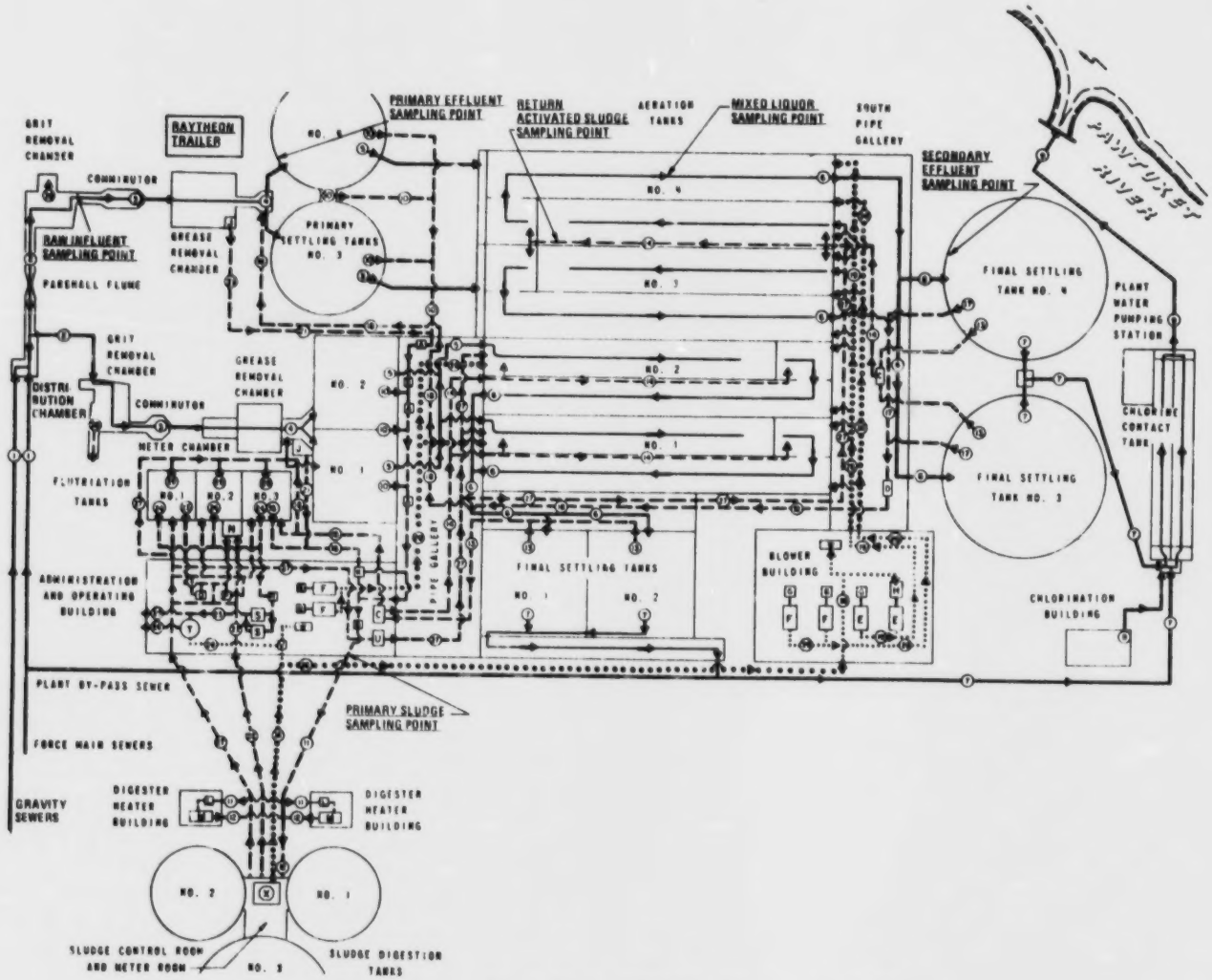


FIGURE 4. SITE DESCRIPTION (Sheet 1 of 2)

A Raw Sludge Pumps
B Sludge Density Meter
C Returned Activated Sludge Pumps
D Waste Activated Sludge Pumps
E High Level Air Blowers
F Low Level Air Blowers
G Motor Drives for Blowers
H Gas Engine Drive for Blower
J Grease Well
K Concentrated or Raw Sludge Pumps
L Heated Sludge Recirculation Pumps
M Sludge Heater
N Sludge Well
P Digested Sludge Pump
Q Elutriated Sludge Pump
R Filter Pumps
S Conditioning Tanks and Vacuum Filters
T Sludge Incinerator
U Supernatant Liquor Pumps
V Digestion Gas Booster Pump
W Plant Heater
X Waste Gas Burner

LIQUIDS SHOWN THUS: ⟶
SEWAGE SOLIDS SHOWN THUS: —→
GAS SHOWN THUS: ●●●●▶

1 Raw Sewage Influent to Treatment Plant
2 Raw Sewage Influent to Grit Removal Chamber
3 Comminutor Effluent to Grease Removal Chamber
4 Grease Removal Effluent to Primary Settling Tanks
5 Primary Effluent to Aeration Tanks
6 Aeration Effluent to Final Settling Tanks
7 Final Effluent to Chlorine Contact Tank
8 Chlorine Influent
9 Treatment Plant Effluent to Pawtuxet River
10 Raw Sludge or Scum from Primary Settling Tanks
11 Sludge or Grease to Sludge Heater
12 Heated Returned Sludge to Digest Tanks
13 Activated Sludge from Final Settling Tanks
14 Returned Activated Sludge to Aeration Tanks
15 Waste Activated Sludge to Concentration Tank
16 Concentrated Sludge to Sludge Water
17 Waste Activated Sludge from Final Settling Tanks
18 Waste Activated Sludge to Primary Settling Tanks
19 High Level Air to Aeration Tanks
20 Low Level Air to Aeration Tanks
21 Grease to Sludge Heater
22 Digested Sludge to Elutriation Tanks
23 Elutriated Sludge - Tank No. 1 to Tank No. 2
24 Elutriated Sludge to Vacuum Filters
25 Filtered Sludge to Truck or Incinerator for Disposal
26 Ash from Incinerator to Truck
27 Supernatant Liquor from Sludge Digestion Tanks
28 Sludge Digestion Gas to Plant Heaters and Incinerator
29 Elutriate to Primary Settling Tanks
30 Grit Removal

NOTE: Plant Water Piping, By-passes and Tank Drains are not shown.

Figure 4. Site Description (Sheet 2 of 2)

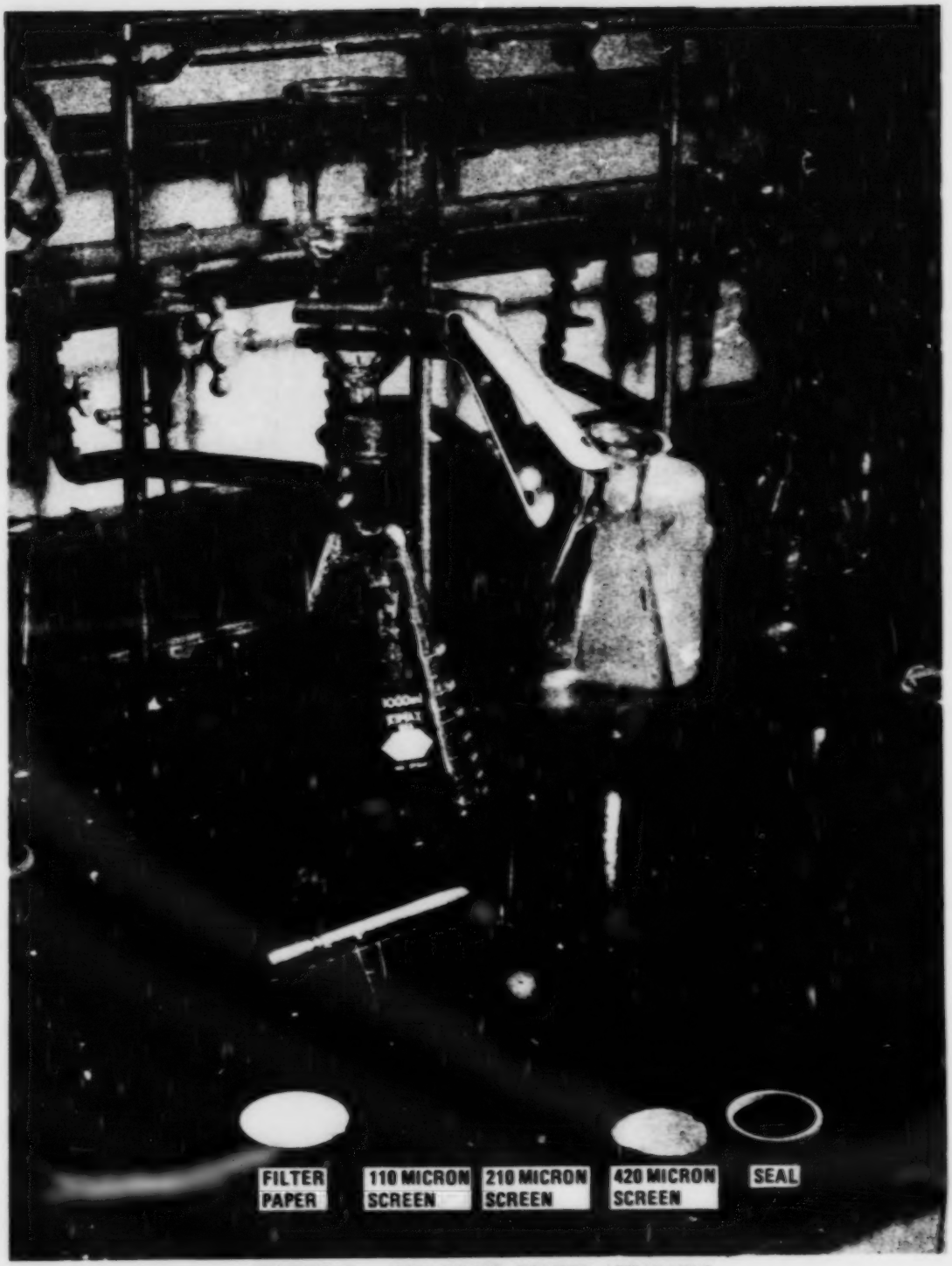


FIGURE 5. MILLIPORE FILTER APPARATUS

Microscopic examination with a Bausch and Lomb microscope (#XL10ZU-FW with 100-power magnification) was used to study particle-size distribution; however, it did not yield quantitative data as to particle-size reduction. The microscopic data were quite subjective since they varied significantly from individual to individual. In addition, the field of view was quite limited, and any single determination could be influenced by the occasional presence of large particles. In essence, the volume of sample examined (one drop) was too small to yield good results. Therefore, this method was abandoned for particle-size determination, but was retained to confirm conclusions from other methods.

Sieve analyses were carried out with a commercially available sieve assembly (Figure 6). These sieves were too heavy to be accurately weighed using laboratory balances; therefore, results from initial tests proved unsuccessful.

Further Tests of Particle Size

With all the selected tests yielding inconclusive and unreliable results, Raytheon had to devise its own method to determine particle size.

The utilized method consisted of filtering a sample through a series of wire mesh filters. The filtration was conducted such that the sample passed through the filters in the direction of coarse to fine. The filters were dried and tared prior to use, and the dry weight was again determined after filtration. The weight of solids retained on each screen was used to characterize the particle-size distribution in the sample. Three sizes of screen were used: 420 μm, 210 μm and 110 μm. The filtration was carried out in the modified Millipore filtration apparatus (Figure 5). This method proved very satisfactory and reliable.

Figure 7 demonstrates how typical data were utilized; it also demonstrates particle-size reduction on a percentage basis. As can be seen from inspection, the particle-size distribution changed drastically when the homogenizer was used. A comparison of one point on the curve (e.g., 420 micrometers) indicates that unprocessed raw sewage possessed approximately 87% of its solids with particle sizes equal to, or less than, 420 micrometers. With a single homogenization this number increased to 99.2%. Along with this determination, suspended solids values were also obtained. In each case, the values for total suspended solids before and after homogenization agreed within 2%, proving that no appreciable loss in solids occurred as a result of the conditioning process. This type of evaluation was performed on the six streams in question: a) secondary effluent, b) primary effluent, c) raw influent, d) mixed liquor, e) return activated sludge, and f) primary sludge.

Discussion of Particle-Size Testing

Good particle-size reduction data were obtained for all six streams. However, for effective sampling of mixed liquor, return activated sludge, and primary sludge, the samples had to be diluted prior to introduction into the homogenizer because these streams were very high in particulate matter and also very viscous, making it inadvisable to pump these streams with a Hydr-O-Grind. Dilution pumps were not available for this phase of the project;

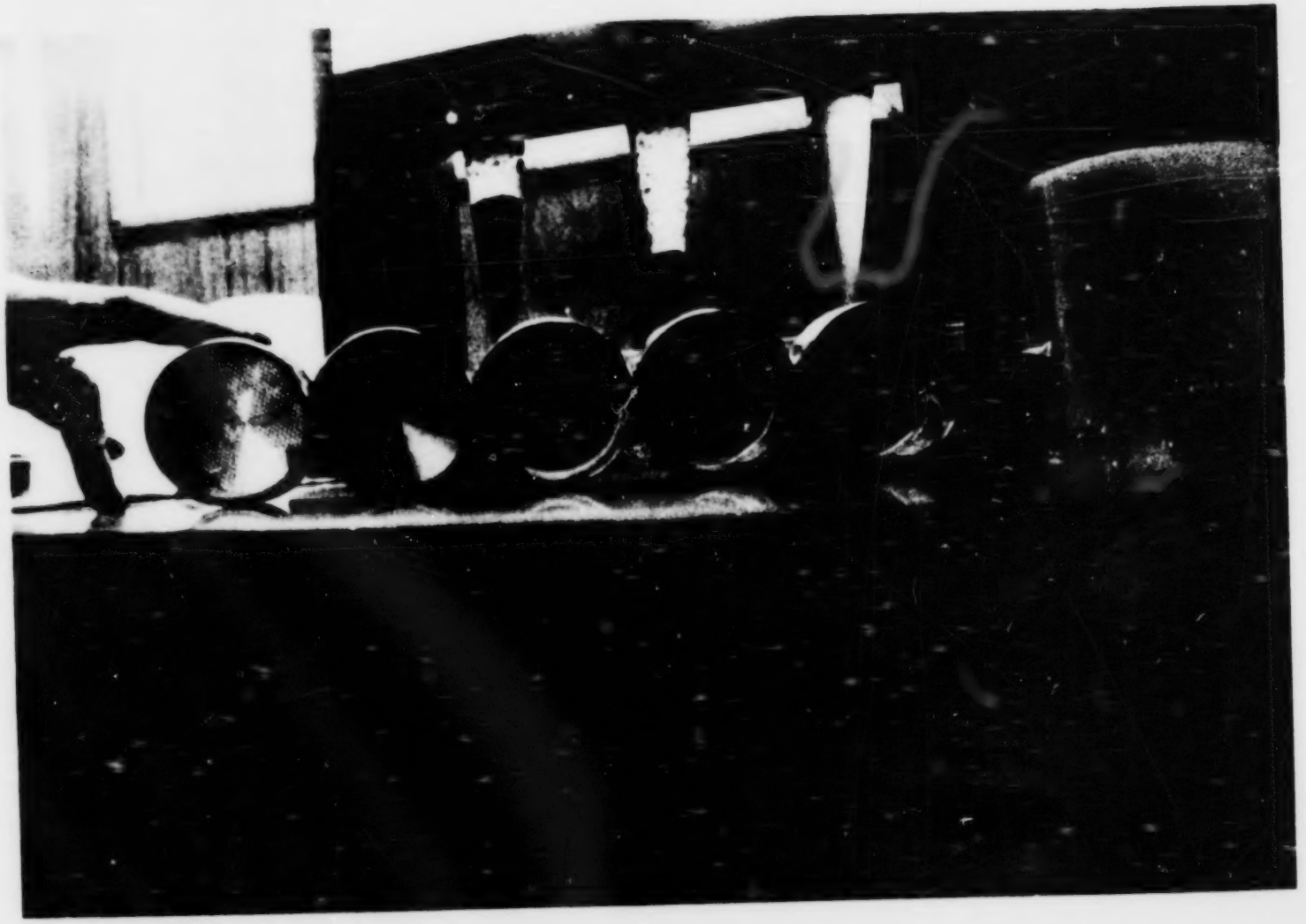


FIGURE 6. SIEVE ASSEMBLY

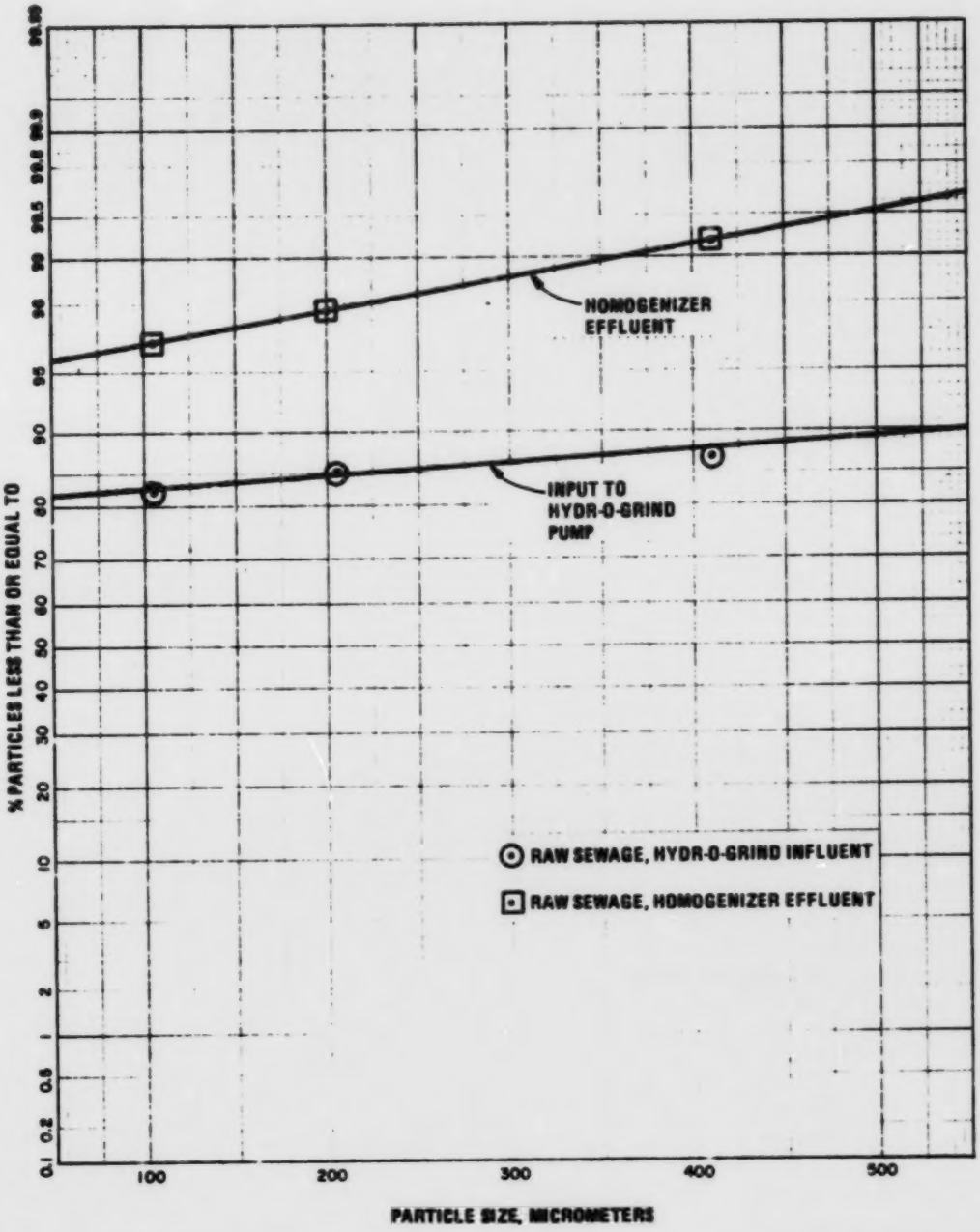


FIGURE 7. RAW SEWAGE, PARTICLE-SIZE REDUCTION WITH HOMOGENIZER

therefore, dilution was accomplished by hand to prepare the input sample to the homogenizer for particle-size reduction tests for these streams. The results from these tests proved the acceptability of sample dilution prior to homogenization.

By using sample dilution at the source, high solids loading within transfer lines was avoided, and the probability of successful sample transfer was increased. The method used will be covered in the "Final System Design" Section of this report.

Demonstration of good particle-size reduction only proves that effective conditioning of a sample for TOC analysis can be accomplished. Questions arise, however, whether or not solids have been lost in the conditioning process, or will be lost during transfer from homogenizer to analyzer. To demonstrate that no solids were being lost, TOC analyses were conducted, utilizing the Beckman 915 Total Organic Carbon Analyzer. The TOC of the sample stream was measured in the vicinity of the Hydr-O-Grind pump. This TOC value was compared with the TOC value of the Hydr-O-Grind effluent and also with the TOC value of the Homogenizer effluent; such comparisons demonstrated no loss in TOC and proved that transfer of the sample can be performed effectively.

Table 1 demonstrates quite vividly that, in every instance, integrity of chemical composition is preserved from the sample's point of origin through the sample-conditioning step. This data, accumulated from monitoring raw sewage, is typical of data obtained by sampling the other five process streams.

TABLE 1

PRESERVATION OF THE INTEGRITY OF CHEMICAL COMPOSITION DURING THE COURSE OF TRANSPORT AND CONDITIONING OF RAW SEWAGE

Date	Source	TOC, mg/l	Ortho-PO_4, mg/l	NO_3, mg/l
1-14-74	Grinder influent	310	6.52	8.3
1-14-74	Grinder effluent	305	7.67	8.3
1-14-74	Homogenizer effluent	280	6.30	8.3
1-15-74	Grinder influent	510	9.72	8.2
1-15-74	Grinder effluent	495	10.19	8.14
1-15-74	Homogenizer effluent	500	9.72	7.32
1-17-74	Grinder influent	335	6.55	5.42
1-17-74	Grinder effluent	335	6.44	5.72
1-17-74	Homogenizer effluent	340	6.41	5.52

Pipe-Size Consideration

Sample flowrate and pipeline size are related because, taken together, they determine sample velocity; hence, they must be considered together. The sample-line size must be large enough to give assurance that there will be no plugging or clogging anywhere within the sample train. However, the line size must also be small enough to furnish high transport velocities so that complete transfer of suspended solids is assured. Obviously, upward velocities of particulate matter in any vertical section of the sampling train must well exceed the settling velocity of the maximum size particle to be sampled.

Settling of solids is an important consideration. Sizing of transfer pipes to obtain sample velocities that will preclude settling of solids was one of the design goals addressed. An EPA report by Shelley and Kirkpatrick[2] states that the minimum line size for transfer of samples from a stream or combined sewer should be 3/8 to 1/2-inch (9.53 to 12.7 mm) inside diameter. Also stated was that minimum line velocities should be in the 2 to 3-ft/sec (.61 to 91-m/sec) range.

With these basic guidelines defined, the transfer lines were selected. In all cases a minimum velocity of 2 ft/sec (.61 m/sec) was strived for, but this value could not always be obtained. However, no transfer-line contamination due to settling was noticed during the course of this study.

Filter Tests

To demonstrate an effective filtration apparatus, Raytheon set up a two-stage filtration unit. The first stage consisted of a self-cleaning wash-flow filter which served to eliminate the larger particles; the second stage was a down-flow filter which consisted of a fixed-media bed which further reduced the sample's particulate matter to a diameter of 12 micrometers, or less. Flow was supplied by the grinder pump to the filter block which housed a nominally rated, 10-micrometer, nylon filter disk. Sample across the filter disc is continuous at a rate of 3 gal./min (11.35 l/min). A small portion of this flow is drawn through the nylon,wash-flow, disc filter using a peristaltic pump adjusted to 20 ml/min. This pump in turn feeds the fixed-media gravity filter. The final filtrate is collected in an overflow cup from which the sample is drawn by the various analyzers.

Table 2 demonstrates results from the two-stage filter test. As can be seen, suspended solids loading varied a great deal; however, the filtering apparatus was able to remove (worst case) 94.3% of all particulate material in the stream with an average removal of 97.5%.

TABLE 2

RESULTS OF FILTER TEST

Suspended Solids Loading, mg/l	Particulate Material Removed, %
440	97.1
520	98.1
570	97.7
580	98.8
610	94.3
620	98.7
650	96.9
680	98.6
1100	99.4
1160	98.5

Some Observations

In addition to providing the necessary flows, the preliminary manifold proved to be an invaluable design vehicle for establishing design "ground rules" such as the following:

1. Ball valves should be used only in a full-on or full-off position. Intermediate positions cause dead spots in the flow passages, and this eventually causes line plugging.

2. Solenoid valves are prone to plugging and therefore are unreliable.

3. Settling in transfer lines is virtually eliminated if no sharp restrictions or stagnation points exist in the lines and if transfer velocities are maintained at no less than 2 ft/sec (.61 m/sec). For instances where this is not feasible, it should be experimentally determined if lower transfer velocities are acceptable.

Preliminary Conclusions

From the results of the preliminary tests, certain conclusions could be drawn:

1. Use of Hydr-O-Grind pumps eliminates the need for homogenization prior to transferring samples over long distances. This confers significant cost advantages, particularly for those applications requiring continuous sampling of numerous process streams.

2. The Hydr-O-Grind pump reduces particle sizes sufficiently to enable quantitative sample transfer and efficient operation of only a single, centrally located, homogenizer unit.

3. The Raytheon homogenizer effectively reduces particle sizes for on-line TOC analyses without unacceptably altering the sample's chemical composition.

4. The filtration unit removes an average of 97.5% of all particulate matter in a flowing stream, and produces a filtrate possessing a maximum particle size of 12 micrometers.

5. The measured temperature rise through the homogenizer is less than one degree Celsius.

6. The measured pressure drop through the homogenizer is 2 psi (13.79 kN/sq m).

SECTION VI
FINAL SYSTEM DESIGN

Establishing a Sampling Procedure

Following the design specifications established in Phase I, Raytheon set out to design an effective sampling system that would be continuous, reliable, and easily maintained without altering the chemical composition of the original sample. The first step was to establish a sampling matrix capable of guiding the collection of data required to properly test the system. Table 3 illustrates this matrix.

TABLE 3

SAMPLING MATRIX

	*Sampling Points					
Chemical Test	Sec. Effl. (1)	Prim. Effl. (2)	Raw Infl. (3)	Mixed Liq. (4)	Ret. Act. Sludge (5)	Prim. Sludge (6)
Total organic carbon	X	X	X	X	X	X
Soluble organic carbon	X	X	X			
Orthophosphate	X	X	X			
Hydrolyzable phosphate	X	X	X			
Ammonia nitrogen	X	X	X			
Nitrate	X	X	X			
Nitrite	X	X	X			

*Streams are listed in order of expected contaminate concentration and were sampled in this order, as mentioned earlier in the text.

From Table 3 it can be seen that streams 1, 2, and 3 (secondary effluent, primary effluent, and raw influent, respectively) demanded the majority of the sampling requirements. Since the sampling-system design was greatly influenced by these requirements, answers to the following questions were required before system design could proceed:

1. How can one analyzer monitor TOC and soluble organic carbon (SOC) for the same stream?

2. What are the optimum modes of operation for the colorimetric analyzers and Pretreatment Unit after sampling of stream (3) has been completed; i.e., while streams (4), (5) and (6) are being sampled?

3. Can the system handle high solids loadings without adversely affecting either data reliability or the system's self-cleaning capabilities?

4. Is any flushing of the sampling manifold and/or the transfer lines needed? If so, then what are the flushing requirements?

Monitoring Both TOC and SOC

To solve the problem of monitoring both TOC and SOC for the same stream, Raytheon modified its "Model 2600" on-line TOC analyzer by adding a second rough sample pump within the analyzer. For the first cycle (i.e., secondary effluent sample), the "Model 2600" monitored TOC by utilizing the rough sample pump connected to the homogenizer output. Upon command from the control panel, that pump was shut off. The second pump (connected to the Pretreatment Unit output) was then turned on, and a filtered portion of secondary effluent sample was supplied to the "Model 2600" for SOC analysis, and to the various colorimeters for determinations of phosphate, ammonia, and nitrate/nitrite. Following completion of this first cycle, the system was switched to the next sampling point (i.e., primary effluent) and the first cycle was repeated. This sequence also was followed for the raw influent sample.

On completion of the third sample cycle (raw influent), no further colorimetric or SOC analyses were required; only TOC monitoring was required for streams 4, 5, and 6. A decision had to be made as to what modes the Pretreatment Unit and colorimeters would be left in during the interim because, if the units were shut down for the three hours required for analyzing streams 4, 5, and 6, subsequent startups would require operator attention. Therefore, it was decided to continue operating the units, but to use flush water as the "sample" stream. This approach yielded a twofold benefit:

1. The analyzers would not be operating without sample input (That type of operation is not recommended).

2. The analyzers would automatically record a zero point during each complete run provided the flush water were not contaminated.

Following the completion of cycle 6, an additional cycle was employed, whereby the sampling manifold, the homogenizer, and its associated plumbing were all flushed with tap water. The flush lasted for only one cycle interval; after which, the system was again ready to start sampling and conditioning Sample No. 1 (secondary effluent). It should be noted that each cycle could be aborted at any time by switching to the manual mode.

System Description

The resultant flow diagram for the sample transfer and conditioning system is shown in Figure 8. The system, which was designed for simple construction and operation, has two modes of operation: automatic and manual. Sample sequencing in the automatic mode is controlled by a timer which can be adjusted for cycle times of 1 to 60 minutes. A second timer was incorporated to start a data acquisition system for automatic data logging.

The sample-switching system consists of pairs of motorized ball valves which operate in tandem to select a sample for analysis upon a command from the control panel. At any given time, each sample is connected (via the valve pairs) to one of two manifolds: sample manifold or drain manifold.

Both manifolds are fabricated utilizing standard PVC fittings chemically bonded together so that all joints provide the minimum amount of obstruction to the flow. The motorized ball valves are also PVC and have union-type pipe connections. This type of valve connection allows for easy disassembly of either the manifolds or the valves should a problem arise. The assembled system, plus the more important sub-systems, are shown in Figures 9 through 13.

The sampling assembly is supplied with samples from six remote points, utilizing Hydr-O-Grind pumps for streams 1, 2, and 3 (Figure 14) and duplex dilution pumps for streams 4, 5, and 6 (Figure 15). Each sample stream is continuously fed to the sampling assembly; however, only one stream can be monitored at a time. Therefore, the other five sample streams are directed to the drain manifold, and back to the head of the plant. This bypass system[3] keeps all the sample streams constantly flowing, and eliminates deadending (Deadending a stream results in a stoppage of flow and possible deposition of particulate matter. If a deadended stream were selected for monitoring, good quantitative data could not be obtained because of the excessive suspended solids loading that would occur when the flow started up again. Such a sudden scouring of the lines could easily produce a temporary, but heavy, overload of suspended particles that might also impair the long-term performance of the homogenizer, Pretreatment Unit or automatic analyzers). A second benefit conferred by a bypass system is a reduction in the time lag required for system purging by the next sample to be analyzed. The bypass system thus has greater useable analytical time because of greatly diminished purge times.

Use of Dilution

Another important aspect of the sampling system is the manner in which mixed liquor, return activated sludge, and primary sludge are conditioned and transported. Raytheon utilized the dilution concept in sampling these three streams for the following reasons:

1. TOC values in streams 4, 5, 6 were much higher than in streams 1, 2, and 3; therefore, the need for a second TOC analyzer (or an analyzer capable of automatic range selection) was eliminated.

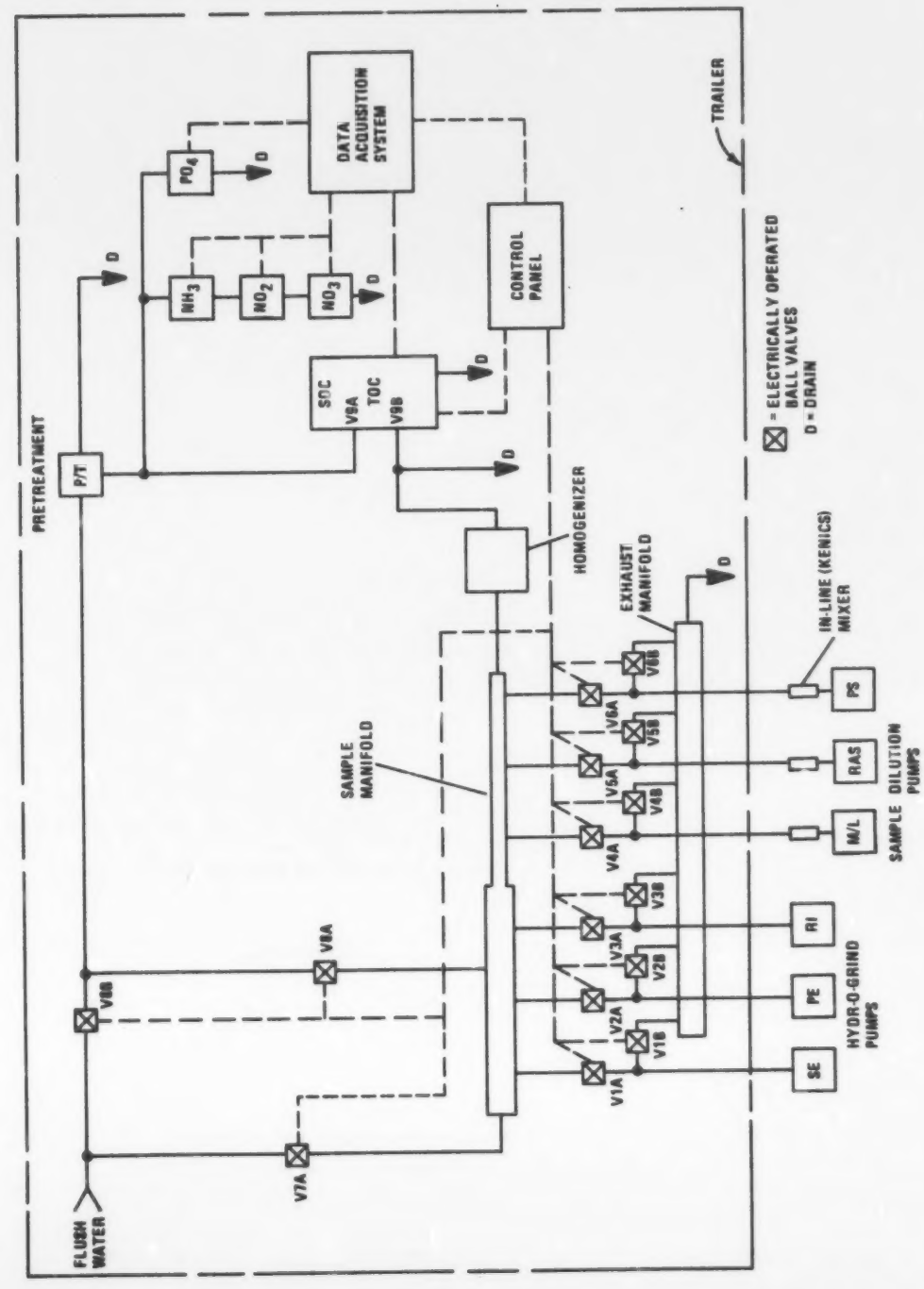


FIGURE 8. FLOW DIAGRAM OF THE SYSTEM

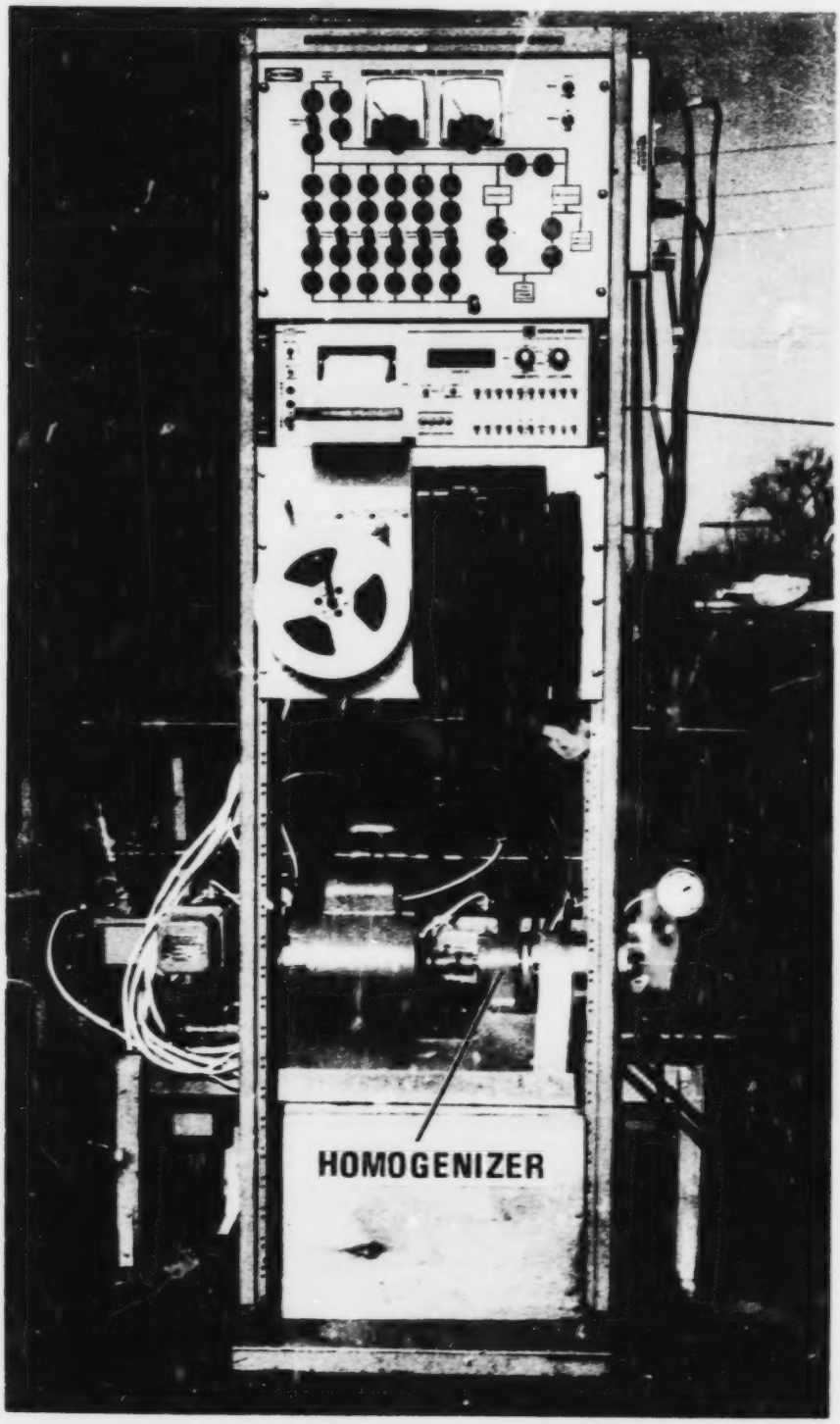
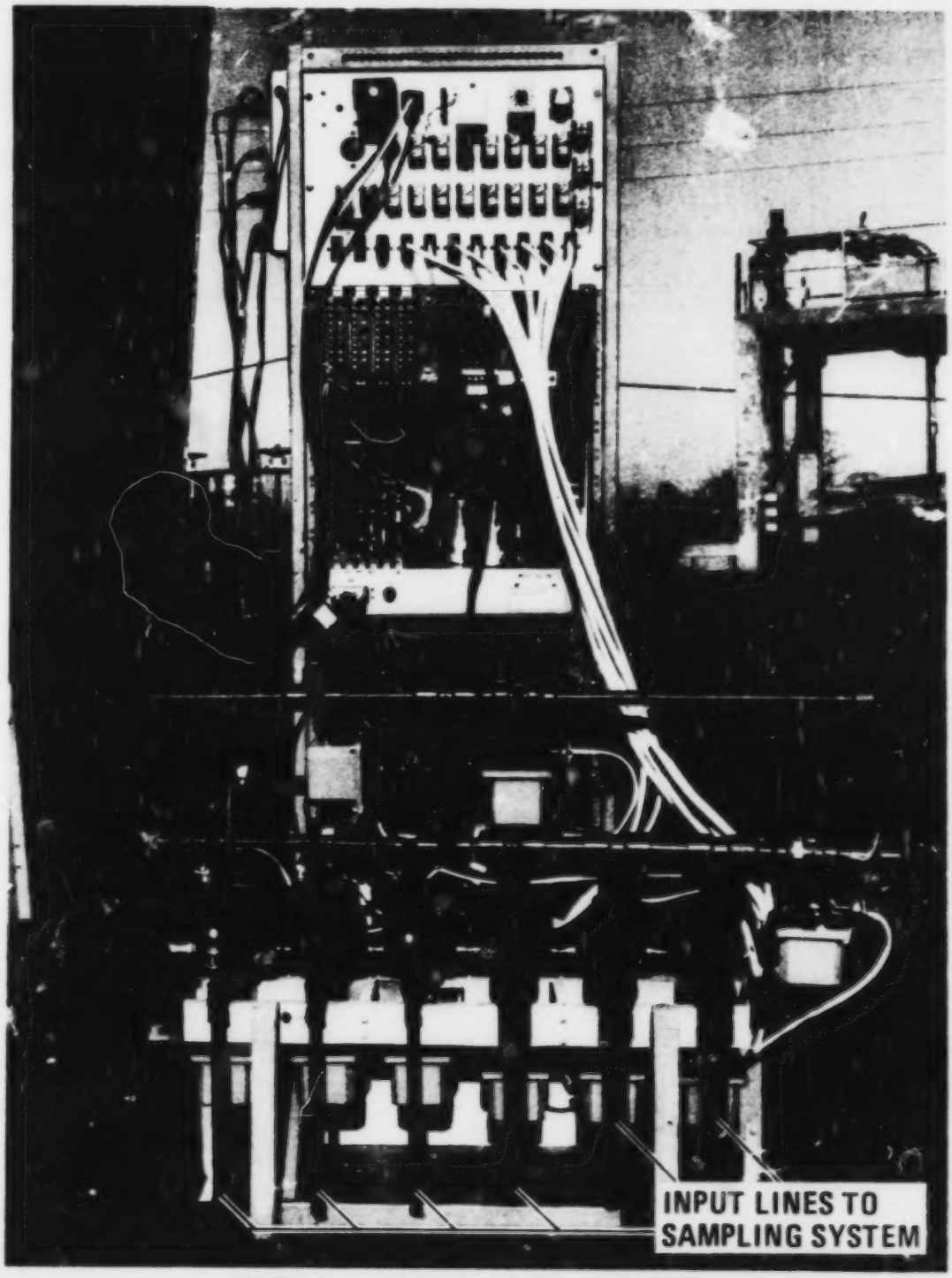


FIGURE 9. SAMPLING SYSTEM, FRONT VIEW



FIGURF 10. SAMPLING SYSTEM, REAR VIEW

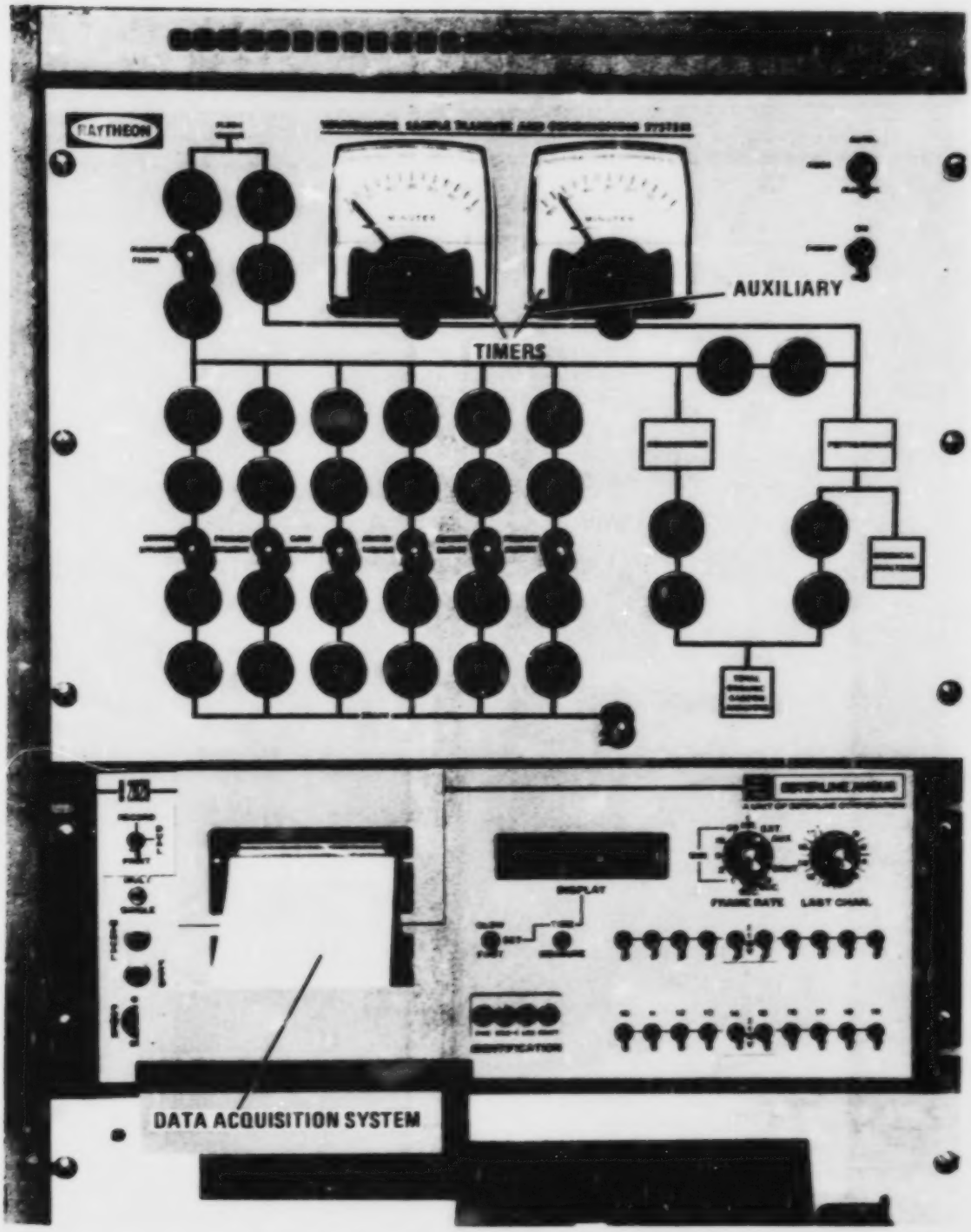


FIGURE 11. CONTROL PANEL, FRONT VIEW

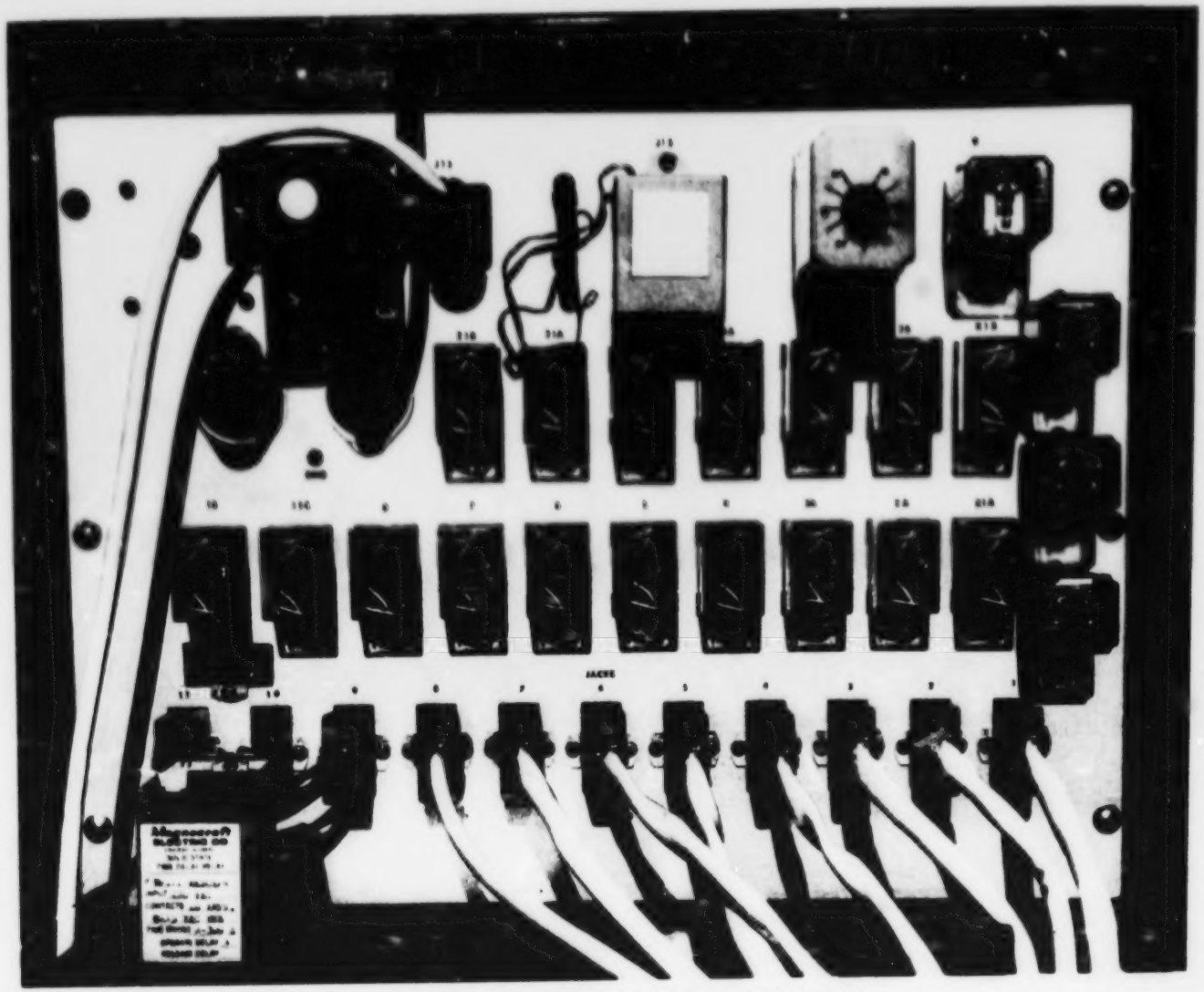


FIGURE 12. CONTROL PANEL, REAR VIEW

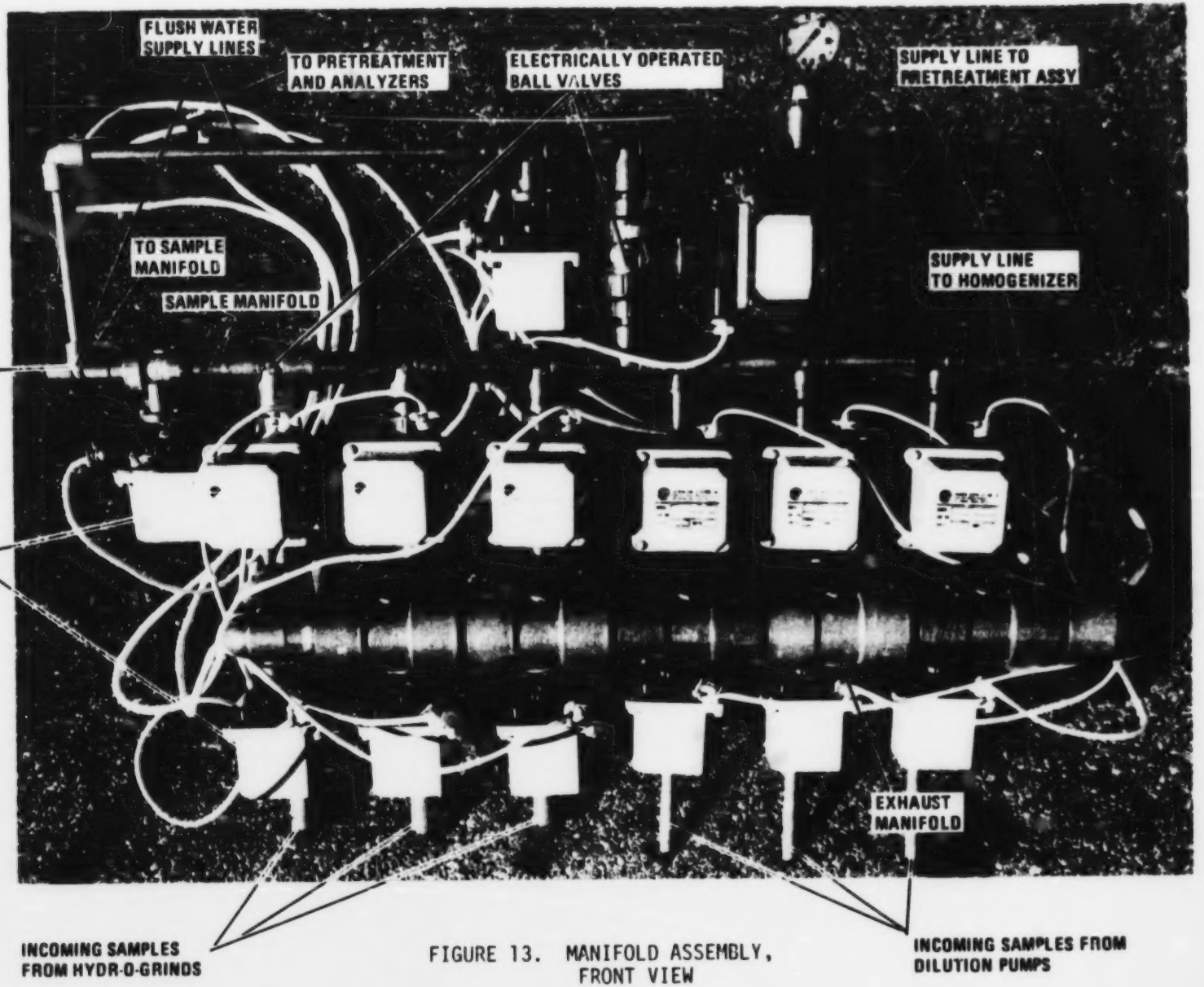

FLUSH WATER SUPPLY LINES
TO PRETREATMENT AND ANALYZERS
ELECTRICALLY OPERATED BALL VALVES
SUPPLY LINE TO PRETREATMENT ASSY
TO SAMPLE MANIFOLD
SAMPLE MANIFOLD
SUPPLY LINE TO HOMOGENIZER
INCOMING FLUSH WATER
ACTUATORS FOR ELECTRICALLY OPERATED BALL VALVES, IN TANDEM
EXHAUST MANIFOLD
INCOMING SAMPLES FROM HYDR-O-GRINDS
INCOMING SAMPLES FROM DILUTION PUMPS

FIGURE 13. MANIFOLD ASSEMBLY, FRONT VIEW

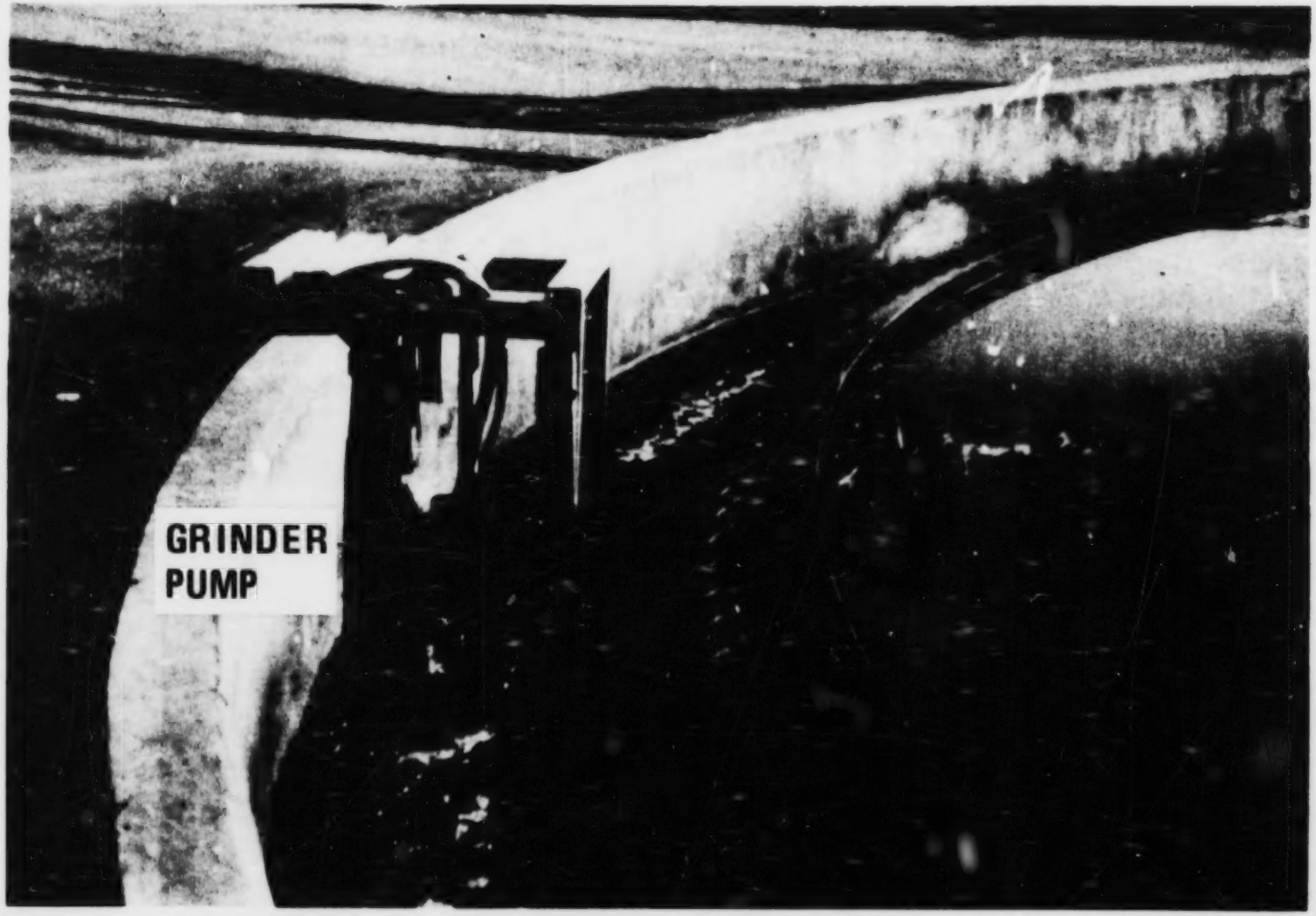


FIGURE 14. TYPICAL HYDR-O-GRIND PUMP INSTALLATION

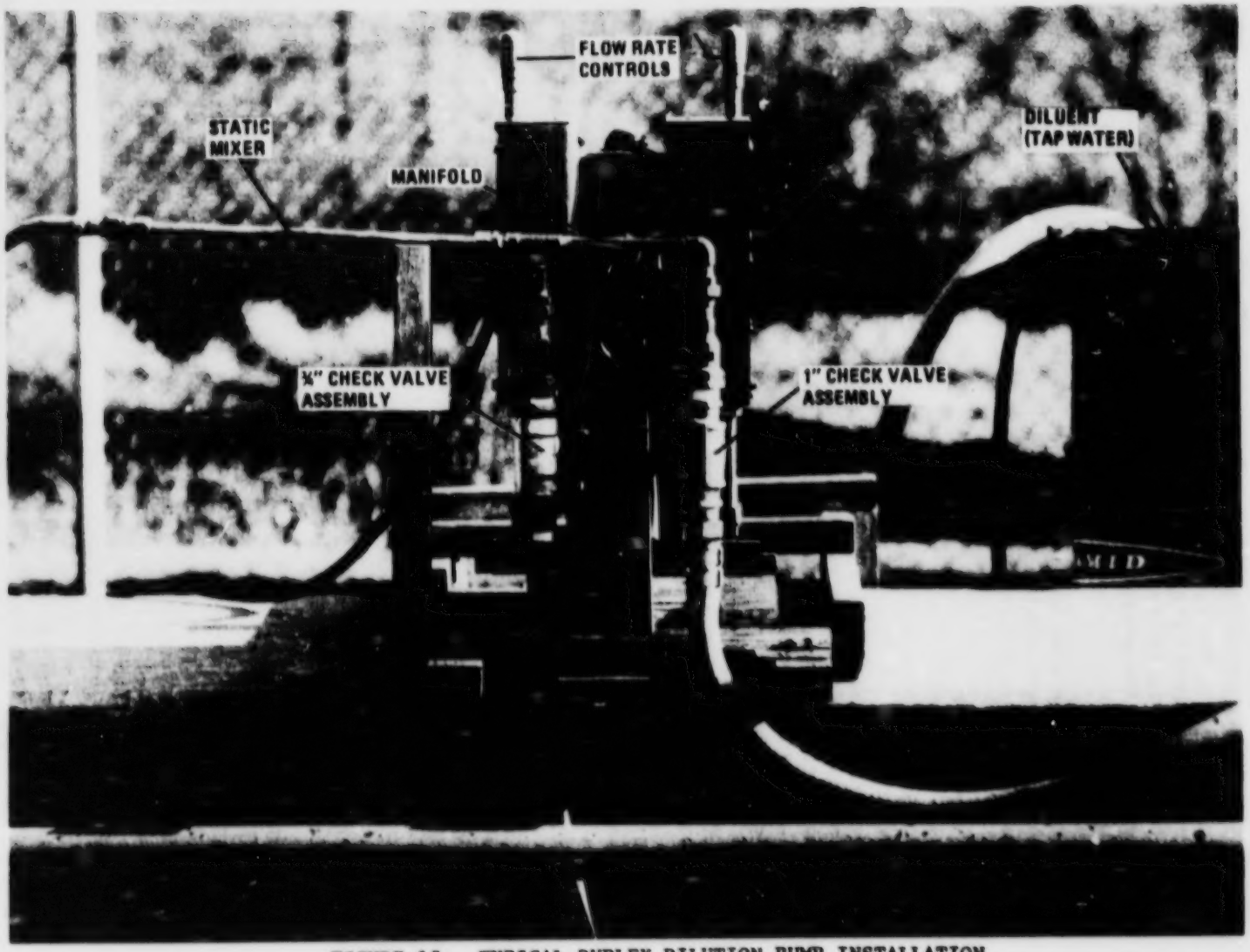


FIGURE 15. TYPICAL DUPLEX DILUTION PUMP INSTALLATION

2. Because suspended solids concentrations were so very high for streams 4, 5, and 6, if these streams had been transported in undiluted condition, the risk of sample-line contamination would have been significantly increased. This would have affected the success of the program by reducing the likelihood of accurate measurement.

Dilution systems have been applied previously[1] to analyzer inputs (i.e., after the samples had already reached the analyzer). While this approach may have been acceptable for sample analysis, sample-line contamination was always a problem.

The decision was therefore made to dilute at the source, rather than at the analyzer interface, to minimize solids loading in the transport lines. The streams were diluted in such a way that they approximated the physical characteristics of primary effluent. A BIF, Series 1722, Duplex "Propsuperb" metering pump was selected because of expected quick delivery and estimated suitability for this application. The pump is a positive-displacement hydraulically-actuated diaphragm pump, with a manually adjustable stroke to change the flowrate. The pump has two sides which act independently, but which are driven by a common drive. This arrangement assures a constant dilution ratio even though the drive speed varies. A typical installation of a dilution pump has already been illustrated by Figure 15; that illustration shows the monitoring of mixed liquor at an aeration basin. The sample dilution ratio was 1:5. The sample stream was drawn through the 3/4-in. (19-mm) check-valve assembly on the left side of the pump, while the diluent (tap water) was drawn through the 1-in. (25-mm) check-valve assembly on the right. Both streams were fed into a common manifold.

The resultant output was a pulsating non-homogeneous flow of both sample and diluent. An in-line static mixer (Kenics P/N 37-08-136) was installed at the pump discharge to counteract this phenomenon. This proprietary in-line mixing assembly employs a series of fixed helical elements enclosed within a tubular housing. The internal geometric design of the unit produces a unique pattern of simultaneous flow division and radial mixing.

Subsequent to static mixing and transfer to the trailer, the sample was homogenized just prior to TOC analysis.

Adapting the Dilution Pump

To install a pump of this type, certain preliminary tests must be performed and certain conditions must be maintained. Initially, for each specific application, a performance curve (output vs. control setting) must be experimentally obtained by each pump after it has been installed. The dilution ratio can then be set by adjusting the pump strokes according to the empirically developed performance curves.

This particular type of positive displacement pump requires a non-varying back-pressure to operate reproducibly. When the back-pressure is low or variable, erratic operation occurs. A back-pressure valve is normally

installed to provide unvarying back pressure. However, this would also place an undesirable obstruction in the discharge line. To simulate back-pressure but eliminate the unwanted obstruction, additional (i.e., excessive) lengths of hose were used on the discharge side of the pump to create back-pressure by increasing the head-loss across the sample line. This simple modification solved the back-pressure problem.

In addition to being back-pressure sensitive, the pump was found to be input-pressure sensitive. The pump relies on proper check-valve sealing to get proper pumping action. Therefore the pump will not operate acceptably if there is positive input pressure. As a result, this type of pump has to draw its feed from a sample reservoir which is essentially at ambient atmospheric pressure. If the sample is being piped under pressure, as was the case with the return activated sludge and primary sludge, the pump cannot be connected directly to the pipe. The sample must first drop into an overflow reservoir (i.e., cup) that is constantly being fed with fresh sample, then the pump will draw the sample as required from the reservoir.

Initial results demonstrated a fair amount of intermittent flow (i.e.. flow discontinuities and stoppages) caused by the presence of fibrous material in the stream. The fibrous material affected the sealing capabilities of the check valve and prevented proper pumping. Cleaning of the check valves brought the pump back on-line.

The problems encountered using these pumps are characteristic of all pumps using check valves.

Overcoming Intermittent Flow

Intermittent flow can be minimized, if not eliminated, by using low dilution ratios; i.e., relatively high flows through the "sample side" of the pump. If dilution ratios are selected so that sample flowrates are high, the subsequent flow velocities through the pump's check valves are also high; such relatively high velocities are advantageous because they increase the tendency of fibrous material to pass cleanly through check valves.

A slightly different approach was tried to monitor primary sludge. From tests conducted in the Preliminary Phase, the TOC values were high and dilutions of 100:1 were anticipated. With dilution ratios that high, it was a certainty that sample flowrate would be very low. As mentioned previously, this is not desirable. Hence, the same type of pump was used, but it employed a variable-speed D.C. motor rather than a fixed-speed A.C. motor. This arrangement makes possible total flow changes without altering the dilution settings, and this in turn affords the operator greater latitude for establishing optimum pump-operating conditions.

The particular piping configuration at the Cranston site generated a unique, primary sludge, sampling problem: the high solids level of primary sludge (5-6% by weight) prevented continuous flow of sample to a reservoir. Many different piping configurations were tried, but continuous flow could not be attained. Without major rework of the plant's piping and an accompanying disruption of plant operation to gain access to unthickened primary sludge,

this problem could not be rectified. The basic sample-taking concept is valid, however. The primary sludge was only one of the six sample streams involved in this project, and it had only one parameter of interest (TOC); therefore, monitoring of this stream was a very small part of the total program, and deletion of this sample stream detracted only modestly from the main purpose of the project. There is no reason to suspect that primary sludge, properly supplied to a dilution assembly of the type described above, would cause any significant problems during dilution, transfer, conditioning, and analysis. The EPA concurred with our decision to delete primary sludge sampling, particularly since control of this plant was out of our hands.

Timing of Samples

Timing is an important, but easily overlooked, consideration in the design of a stream-switching system. Of course, the frequency at which each point is analyzed must be acceptable to process-control requirements. In addition, the dwell time on each sample must be of sufficient duration to purge the sample manifold and passageways into the analyzers, and to allow sufficient time for analyzer response. There are three times which must be addressed: a) transfer time, b) conditioning time, and c) analyzer response time.

Transfer times were obtained by measuring the flowrate of each pump and by using the appropriate formula for the velocity in each line. With the transfer velocities and distances known, transfer times were easily calculated. These data are shown in Table 4.

TABLE 4

SAMPLE-TRANSFER DATA

Sample Stream	Flow rate, gal/min (l/min)	Flow Velocity, ft/min (m/min)	Transfer Distance, ft (m)	Transfer Time, Min
Secondary effluent	4.87(18.4)	119.8(36.2)	475(144.8)	3.95
Primary effluent	5.46(20.6)	114.7(44.1)	55(16.8)	.38
Raw influent	5.82(22.0)	153.0(46.6)	75(22.9)	.49
Mixed liquor	.46(1.74)	79.5(24.2)	210(64.0)	2.64
Return activated sludge	.44(1.67)	75.6(23.0)	250(76.2)	3.30
Primary sludge	---	---	---	---

Because it was unnecessary to separate conditioning time from analyzer response time, these two times were measured in one combined test. To measure the response time of the analyzers in conjunction with sample-conditioning time, a flush cycle was initiated and a stable zero was reached on all monitoring equipment, thus providing a zero datum. Primary effluent was selected manually, and the time was recorded. Within ten minutes the TOC analyzer was reading 100% of final value, but the colorimetric analyzers required forty minutes to reach 100% of the final value. Based on this data, the sample cycle time was set at one hour. Thus, during a one-hour cycle, the sample for TOC is taken from the continuous flow sample stream 30 minutes after preceding portions taken for colorimetric analyses.

Comparisons with Standard Analytical Methods

To assess properly the success or failure of the sampling system, manual grab samples were taken and analyzed by standard methods; these values were also compared with the corresponding values obtained from the automatic analyzers in order to determine analyzer performance. To assure a valid evaluation of the sampling system, two grap samples were taken: one at the source of the process stream (before any automatic sampling, transferring, or conditioning) to establish a reference point, and a second at either the homogenizer's exit port (interface value for TOC analyzer) or at the filter assembly's exit port (interface value for colorimetric analyzers). Because of the large differences in analyzer response times (ten minutes for the TOC analyzer, and forty minutes for the colorimetric analyzers) it was necessary to take two sets of grab samples at different times.

As previously described, the control system has two timers: one for controlling the sampling cycle and one for starting up auxiliary equipment (i.e., the data-acquisition system). To obtain representative grap samples for comparison with automatic analyzers, the samples had to be obtained in advance of the actual readout times; hence, readout time was established as the last five minutes of each sampling cycle. A grab sampling procedure was established and is shown diagramatically in Figure 16.

Sequence of events during a sampling cycle:

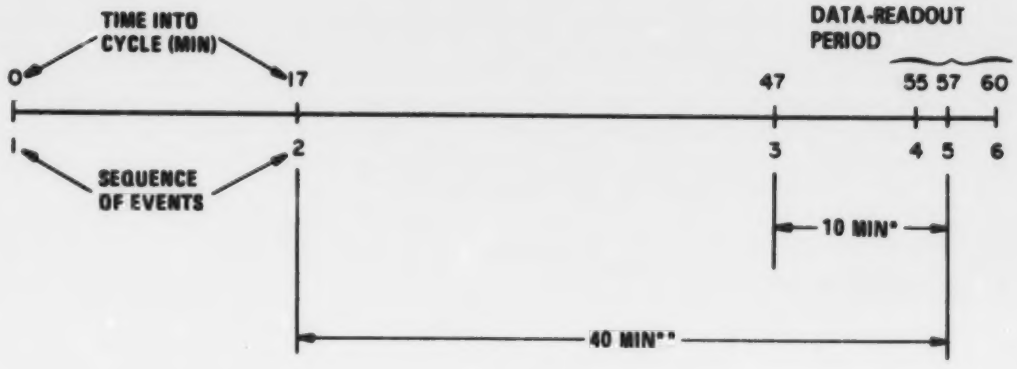


FIGURE 16. SAMPLING SEQUENCE

1. Sample stream selected.

2. Grab samples taken at sample source and from Pretreatment Unit effluent; these were referee samples for the colorimetric analyses and for SOC.

3. Grab samples taken at sample source and homogenizer output; these were referee samples for the TOC analyses.

4. Data-acquisition system was started up, and data were recorded.

5. As of this point in time, analyzer values and the corresponding grab samples should agree.

6. Cycle completed. New stream selected. Data-acquisition system turned off.

NOTE: Sampling sequence is the same for process streams 1, 2 and 3. However, for process streams 4, 5 and 6, only one set of grab samples was taken at event (3) since TOC was the only parameter of interest for these three streams.

For a more detailed description of the system's operationg and maintenance procedures, refer to Appendix B.

* Time lag between sample input to TOC analyzer and the analyzer's corresponding readout of TOC.

** Time lag between sample input to colorimetric analyzers and their corresponding readouts of NH_3, $o\text{-}PO_4$, etc.

SECTION VII
TESTS RESULTS

Reference Tests

With all the equipment installed, operating, and a sampling sequence established and proven, the next step was to establish the referee tests to be performed on the grab samples.

To measure TOC and SOC, a Beckman "Model 915" Total Organic Carbon Analyzer was used. The Beckman "Model 915" analyzes discrete, 50-microliter samples that must be injected into the instrument by means of a microsyringe. Samples containing any significant amounts of suspended matter must be blended, acidified, and sparged prior to injection into the instrument. For this project, referee TOC and SOC samples were manually acidified, and a Waring blender was used to sparge out the CO_2 and simultaneously blend the sample's suspended solids. For colorimetric analyses, methods specified by "Standard Methods for the Examination of Water and Wastewater", 13th Edition, were used:

1. Phosphate - Method 223, "Ascorbic Acid Method"
2. Ammonia - Method 132B, "Direct Nesslerization Method"
3. Hydrolyzable Phosphate - Method 233F with a preliminary hydrolyzation step whereby the sample was acidified to a pH of 1 and the solution was boiled for one hour.

A Bausch and Lomb "Spectronic 70" spectrophotometer was used to perform the manual, colorimetric, reference analyses for orthophosphate, ammonia nitrogen and hydrolyzable phosphate.

Sample Transfer and Conditioning System Test Data

Table 5 shows the test results for the sample transfer and conditioning system when it was evaluated by Raytheon at the Cranston Water Pollution Control Facility. The amount of data collected is sufficient for a preliminary evaluation of the sampling system. Note, however, that most of the erratic data in Table 5 were produced by the various on-line analyzers being employed!

Performance of Automatic Analyzers

TOC, SOC, orthophosphate and ammonia nitrogen were the only parameters monitored "on-line". The on-line hydrolyzable phosphate analyzer did not

TABLE 5. SAMPLE TRANSFER AND CONDITIONING SYSTEM TEST DATA: SECONDARY EFFLUENT (Sheet 1 of 4)

Date (1974)	TOC, mg/l			SOC*, mg/l			o-PO_4, mg PO_4/l			NH_3, mg NH_3-N/l			Hyd. PO_4, mg PO_4/l	
	Source	Interface	Analyzer	Source	Interface	Analyzer	Source	Interface	Analyzer	Source	Interface	Analyzer	Source	Interface
11-5	13.2	13.4	-	14.8	11.8	-	17.1	16.8	16.5	5.1	3.3	-	20.5	7.96
	34.0	33.0	21.5	31.0	33.0	21.0	19.2	18.7	18.4	5.0	3.9	-	20.8	14.4
11-8	30.0	27.0	31.0	20.0	52.0	30.0	18.0	16.0	-	-	-	-	22.8	19.7
							16.6	16.4	17.1	-	-	-	18.3	18.5
11-11	21.0	24.0	19.0	18.0	17.0	13.0	22.5	22.1	23.5	-	-	-	-	-
11-12	22.0	20.0	24.0	16.0	15.0	21.0	20.6	19.8	21.2	-	-	-	22.5	21.4
11-13	26.0	25.0	52.0	19.0	19.0	43.0	17.9	18.0	17.1	15.2	15.4	-	18.7	18.7
							15.8	16.8	16.0	13.4	13.6	-	16.8	17.8
11-14	23.0	21.0	45.0	20.0	18.0	43.0	17.2	16.4	14.4	-	-	23.7	18.2	17.4
							16.4	16.1	17.0	-	-	25.2	17.2	16.9
11-15	-	-	-	-	-	-	17.3	16.6	17.0	15.9	15.6	16.4	18.1	17.4
							17.2	17.0	16.9	-	-	16.4	-	-
11-18	30.0	28.0	29.0	17.0	17.0	20.0	22.6	17.4	20.9	-	-	-	24.2	18.6
							22.1	21.6	22.8	-	-	-	23.6	23.1
11-20	33.0	30.0	25.0	25.0	34.0	22.9	18.4	17.4	17.7	11.8	12.7	-	20.1	18.9
							17.6	17.5	18.0	11.0	10.8	-	18.8	18.7
11-22	30.3	30.3	11.3	22.6	24.3	15.0	13.4	10.8	10.6	16.1	15.6	18.3	-	-
							12.8	11.2	11.8	17.7	16.6	18.6	-	-
11-25	24.0	26.0	30.0	14.0	17.0	26.0	22.0	20.3	19.4	9.5	11.4	17.8	26.4	24.6
							19.5	12.2	20.2	8.96	6.8	9.0	22.4	14.0
11-26	22.0	26.0	20.5	24.0	18.0	21.0	16.7	16.3	17.8	12.1	12.1	18.3	-	-
							17.0	16.5	17.5	11.3	11.2	16.5	-	-
11-27	25.0	22.5	21.0	17.0	17.0	20.5	16.0	15.0	17.8	15.5	14.8	-	16.9	15.9
							16.3	15.9	18.2	14.8	14.1	-	17.1	16.7

*SOC particle size was less than 12 micrometers

TABLE 5. SAMPLE TRANSFER AND CONDITIONING SYSTEM TEST DATA
PRIMARY EFFLUENT (Sheet 2 of 4)

Date (1974)	TOC, mg/l			SOC*, mg/l			o-PO_4, mg PO_4/l			NH_3, mg NH_3-N/l			Hyd. PO_4, mg PO_4/l	
	Source	Interface	Analyzer	Source	Interface	Analyzer	Source	Interface	Analyzer	Source	Interface	Analyzer	Source	Interface
11-5	86.0	93.0	-	106.0	64.0	-	14.9	15.0	15.5	33.0	33.6	-	25.1	20.2
	145.0	131.0	131.0	106.0	101.0	105.0	15.0	14.7	15.1	32.2	32.0	58.5	27.5	21.7
11-8	307.0	109.0	115.0	103.0	104.0	93.0	15.6	14.0	14.6	-	-	-	26.8	24.1
11-11	125.0	113.0	81.0	75.0	55.0	81.0	17.8	17.2	17.4	-	-	-	-	-
11-12	92.0	84.0	133.0	54.0	53.0	128.0	13.8	13.4	13.2	-	-	-	23.4	23.2
11-13	138.0	127.0	197.0	59.0	60.0	213.0	16.0	16.1	15.8	29.2	28.4	-	25.7	20.8
							16.4	16.1	15.9	24.6	25.6	33.8	27.9	23.6
11-14	94.0	94.0	14.0	68.0	66.0	173.0	13.2	12.5	14.1	-	-	46.9	22.2	21.0
							13.5	13.0	15.2	-	-	42.4	22.9	22.9
11-15		-	-	-	-	-	-	-	-	30.0	29.2	36.8	21.7	16.8
							-	-	-	27.2	2.74	-	26.6	21.4
11-18	113.0	107.0	87.5	67.0	95.0	78.0	15.4	15.0	16.1	-	-	-	24.6	24.3
11-20	121.0	126.0	105.0	62.0	83.0	70.0	14.2	13.7	14.3	25.2	25.2	-	22.7	22.1
							15.3	13.4	15.3	25.7	24.3	-	26.8	23.6
11-22	119.0	114.0	19.0	63.0	89.0	107.5	16.2	15.2	15.6	25.8	23.8	33.3	-	-
							19.3	18.3	16.3	23.9	24.0	29.3	32.6	28.2
11-25	133.0	110.0	105.0	49.0	64.0	85.0	20.1	17.4	17.3	28.4	26.7	27.3	30.8	28.9
							18.1	17.0	17.8	27.5	27.7	27.7	-	-
11-26	104.0	109.0	80.0	48.0	73.0	66.0	14.0	12.4	14.2	25.4	25.6	54.3	-	-
							15.4	13.6	15.4	29.9	27.0	58.0	23.3	18.3
11-27	102.0	96.0	80.0	51.0	58.0	61.0	14.3	11.2	15.8	26.8	26.4	-	24.8	22.9
							14.6	13.5	16.8	26.8	26.5	-	-	-

*SOC particle size less than 12 micrometers

TABLE 5. SAMPLE TRANSFER AND CONDITIONING SYSTEM TEST DATA
RAW INFLUENT (Sheet 3 of 4)

Date (1974)	TOC, mg/l			SOC*, mg/l			o-PO_4, mg PO_4/l			NH_3, mg NH_3-N/l			Hyd. PO_4, mg PO_4/l	
	Source	Interface	Analyzer	Source	Interface	Analyzer	Source	Interface	Analyzer	Source	Interface	Analyzer	Source	Interface
11-5	130.0	116.0	-	138.0	53.0	-	13.0	12.9	12.6	22.1	22.8	48.3	25.4	21.7
	172.0	157.0	118.0	97.0	96.0	86.0	14.5	14.4	14.[illegible]	19.4	20.4	29.8	20.2	18.4
11-8	235.0	150.0	140.0	77.0	82.0	124.0	14.4	13.4	14.0	-	-	-	28.8	26.9
11-11	202.0	142.0	137.0	-	-	-	-		-	-	-	-	-	-
11-12	206.0	165.0	203.0	70.0	62.0	213.0	16.1	16.8	14.5	-	-	-	28.9	29.8
11-13	155.0	158.0	240.0	97.0	80.0	223.0	12.3	12.0	11.9	20.7	21.6	25.3	27.5	26.9
							12.8	13.1	12.9	20.4	20.3	21.6	23.6	20.8
11-14	178.0	166.0	245.0	97.0	173.0	205.0	13.2	11.8	-	-	-	-	25.1	22.4
							13.5	13.5	15.5	-	-	30.8	24.3	24.3
11-15	-	-	-	-	-	-	18.1	19.2	17.0	18.0	22.2	26.2	26.6	28.2
							16.3	16.3	15.9	21.2	18.1	16.0	23.0	23.0
11-18	229.0	168.0	113.0	76.0	98.0	85.0	14.2	15.6	20.2	-	-	-	31.2	34.3
11-20	220.0	163.0	119.0	95.0	97.0	105.0	14.9	12.1	16.7	25.2	18.8	-	29.9	24.3
							14.0	12.9	16.7	23.0	21.9	-	27.3	25.2
11-22	153.0	116.0	130.0	-	-	-	15.6	12.5	12.5	22.2	21.5	22.5	-	-
11-25	136.0	116.0	96.0	-	-	-	14.5	13.9	16.8	19.5	21.2	20.4	35.1	38.2
							14.6	14.4	15.0	18.2	18.0	18.2	32.8	32.4
11-26	177.0	132.0	85.0	73.0	84.0	81.0	13.3	12.0	14.6	24.9	24.5	47.8	-	-
							11.6	7.8	12.7	20.4	21.7	43.5	-	-
11-27	139.0	133.0	-	223.0	75.0	81.0	16.5	15.8	18.7	24.0	25.9	-	23.1	24.7
							13.0	13.4	-	19.2	21.1	-	24.7	25.5

*SOC particle size less than 12 mi[illegible]ometers

TABLE 5

SAMPLE TRANSFER AND CONDITIONING SYSTEM TEST DATA
(Sheet 4 of 4)

MIXED LIQUOR				RETURN ACTIVATED SLUDGE			
	TOC*, mg/l				TOC, mg/l		
Date (1974)	Source	Interface	Analyzer	Date (1974)	Source	Interface	Analyzer
11-5	75.0	79.1	97.1	11-5	-	-	-
11-8	142.0	125.0	125.0	11-8	-	-	-
11-11	132.0	153.0	99.0	11-11	-	-	-
11-12	102.0	112.0	162.0	11-12	2530	1450	2080
11-13	120.0	125.0	203.0	11-13	1850	1670	2350
11-14	118.0	149.0	165.0	11-14	2080	2350	2540
11-15	-	-	87.5	11-15	-	-	1950
11-18	114.0	129.0	88.0	11-18	2200	2650	1400
11-20	119.0	115.0	77.5	11-20	2890	3470	2230
11-22	188.0	178.0	183.0	11-22	1510	1970	1950
11-25	151.0	145.0	191.0	11-25	1510	1950	1740
11-26	109.0	35.0	30.0	11-26	2090	2060	1350
11-27	-	-	-	11-27	2050	2320	1300
11-29	120.0	80.0	99.0	11-29	2460	2810	2520
	118.0	99.0	88.2		2510	2530	2358
	127.0	104.0	103.5		2170	2970	2619
					2300	2370	2430

*True value 5 times value in table

NOTE: The "Source" samples for these two tables were composites of several, rapidly collected, grab samples taken directly from the mixed liquor basin, or, from the return activated sludge line. Prior to analysis, each composite was diluted by a factor representing the known dilution factor (i.e., "dilution ratio") of the appropriate on-line dilution pump.

perform reliably and was not used. The data shown for this parameter were obtained by grab sample analyses.

The continuous ammonia analyzer, which has the capability to monitor ammonia nitrogen, nitrate and nitrite with the substitution of different manifolding arrangements and reagents, did not determine ammonia satisfactorily for this project. This ammonia analyzer was equipped by the manufacturer with an outmoded, automatic-analyzer, wet-chemistry system (i.e., direct nesslerization) which greatly promoted rapid fouling of the analyzer's optical components; this, in turn, led to intolerable maintenance requirements and excessive analyzer downtime. A great amount of time was expended on attempting to obtain acceptable on-line ammonia data; hence, little time or funds were left to monitor nitrate or nitrite. These latter parameters finally had to be excluded from the field study.

Comparison of Source and Interface Values

Adequate agreement was achieved between source values and analyzer interface values for almost all streams investigated; i.e., deviations generally fell within the combined errors due to grap sampling and to the standard method of analysis being used (see Appendix A).

The primary effluent stream (stream 2) yielded the most consistent data. This stream was high in suspended and colloidal solids; therefore, small losses or gains of solids as the primary effluent was being transferred did not significantly affect the results.

The secondary effluent, on the other hand, was a very clean stream for which any loss or gain of solids would greatly affect the results. This was particularly true for total organic carbon analyses, and was probably the reason why the standard deviation was greater for the secondary effluent data than for the primary effluent data.

The raw influent values varied for another reason. This stream, at the front end of the plant, was subject to sudden and wide changes in contaminant concentration and composition. The variety and distribution of floating and suspended material made the obtaining of representative samples extremely difficult. As expected, the raw influent stream measurements showed the greatest variance.

Analysis of the data (again see Appendix A) demonstrated that streams containing very high solids concentrations can be monitored effectively when dilution pumps are properly applied.

Test Results from Automatic Analyzers

Although various difficulties, as noted below, were encountered with some of the automatic analyzers, the results obtained helped verify (to a limited extent) the performance acceptability of the sampling, transfer and conditioning system's components and the integrated system's operating reliability. Primarily, however, the performance of most of these automatic on-line analyzers merely emphasized that commercially available and truly reliable

instrumentation of this type (applicable to wastewater-treatment process streams) is severely limited, both in variety and in number of suppliers.

TOC-SOC: Initial TOC problems made it necessary to install two TOC analyzers simultaneously (Raytheon Company's TOC analyzer was ultimately selected for final testing of the sample transfer and conditioning system). Unfortunately, the use of two TOC analyzers in the limited space of the Experimental Trailer brought about an unfavorable positioning of several analyzers, both TOC and colorimetric. This "unfavorable positioning" involved the placement of most of the analyzers further from their sample interfaces than was desirable for optimum results. The TOC measurements, especially, were adversely affected by this situation. It should be noted, however, that these TOC variations were not unidirectional; instead, the data exhibited both high and low biases. Unduly long transfer lines linking TOC interface (i.e., homogenizer effluent) to the TOC analyzer allowed solids to settle out slowly. At first, such solids settling would tend to produce slightly low values. However, when a sufficient amount of solids had settled out and the transfer lines had thus become narrowed and non-uniform in bore, the resultant sporadic increases in sample velocity would suddenly scour the lines and cause entrainment of deposited solids by the sample stream. This in turn would produce occasional "high" TOC values.

Orthophosphate: The orthophosphate analyzer was properly located, hence it operated most consistently. All three values, (source, interface, and automatic analyzer) agreed very well.

Hydrolyzable phosphate: Measurements were not made with an automatic analyzer.

Ammonia nitrogen: The ammonia measurements suffered because of improper placement of the ammonia analyzer, but even more because of random equipment malfunction due to the obsolete wet-chemistry system furnished by the colorimetric analyzer's manufacturer.

Nitrate and Nitrite: Measurements were not taken because the automatic analyzer was devoted almost solely to ammonia-nitrogen samples.

Statistical Analysis

A statistical analysis of some of this project's final test results was conducted by the EPA, and the statistical findings are the bases of the claim for the acceptability of the sample transfer and conditioning system's on-line performance. The statistical analysis is included as part of Appendix A.

SECTION VIII

REFERENCES

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2. Shelley, P.E., and Kirkpatrick, G.A., "An Assessment of Automatic Sewer Flow Samplers." EPA-R2-73-261, June 1973.

3. Houser, E.A., Principles of Sample Handling and Sampling Systems Design for Process Analysis. Instrument Society of America, Pittsburgh, Pa., 1972.

4. American Public Health Association, Standard Methods for the Examination of Water and Wastewater, 13th ed., APHA, New York, 1971.

APPENDIX A - STATISTICAL ANALYSIS

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

SUBJECT: Testing for Statistical Difference Between the Sample Source and the Sample Interface Methods of Data Measurement

DATE: January 7, 1975

FROM: R. G. Eilers and Ella Hall
Systems & Economic Analysis Section

TO: Robert H. Wise
Pilot & Field Evaluation Section

This analysis is intended to determine statistically if there exists any evidence of a systematic difference between the sample source and the sample interface methods for measuring concentrations of TOC, SOC, O/PO_4, NH_3, and HP (hydrolyzable phosphorus) in wastewater. A statistical test was applied to 17 paired sets of measurement data, and the results appear in Table 1.

The reference for this procedure is the book entitled "Statistical Analysis in Chemistry and the Chemical Industry" by Carl Bennett and Norman Franklin, John Wiley and Sons (1966), pages 180-182.

In order to illustrate the statistical theory involved here, a detailed calculation for the TOC-Secondary measurements will be given. The raw data consisted of the following 13 paired measurements along with their respective differences:

Observation	Source	Interface	Difference, d
1	13.2	13.4	-0.2
2	34.0	33.0	1.0
3	30.0	27.0	3.0
4	21.0	24.0	-3.0
5	22.0	20.0	2.0
6	26.0	25.0	1.0
7	23.0	21.0	2.0
8	30.0	28.0	2.0
9	33.0	30.0	3.0
10	30.3	30.3	0.0
11	24.0	26.0	-2.0
12	22.0	26.0	-4.0
13	25.0	22.5	2.5

The mean of the differences, $\bar{d} = .5615$, and the standard deviation of the differences, $s = 2.2948$, are both calculated and Student's t - Test is applied according to the equation:

$$t = \frac{\bar{d}\, n^{.5}}{s} = \frac{.5615\ (13)^{.5}}{2.2948} = \frac{.5615\ (3.6056)}{2.2948} = .8822$$

where $n = 13$ is the sample size with $(n-1) = 12$ degrees of freedom. Referring to the Students t - Distribution Table, the values of $t_{12,.05} = 2.179$ (12 degrees of freedom, 5% level of significance, two-tailed distribution) and $t_{12,.01} = 3.055$ (12 degrees of freedom, 1% level of significance, two-tailed distribution) are selected. Since $|t| = .8822 \leq 2.179$ and $|t| = .8822 \leq 3.055$, it can be concluded that there is no evidence of a systematic difference between the two methods of measurement at both the 5% and 1% levels of significance. What this means, simply, is that if $|t| > 2.179$ the possibility of the two methods being statistically equivalent is only 5% or less. Similarly, if $|t| > 3.055$, the possibility of the two methods being statistically equivalent is only 1% or less.

In practice a level of significance of .05 or .01 is customary, although other values can be used. If, for example, a 5% level of significance is chosen in designing a test of hypothesis (the hypothesis in this case is that the two methods are statistically equivalent), then there are about 5 chances in 100 that the hypothesis would be rejected when it should be accepted, i.e., 95% confidence exists that the right decision has been made. In such a case it is said that the hypothesis has been rejected at a .05 level of significance, which means a .05 probability of being wrong.

TABLE 1

RESULTS OF STATISTICAL COMPUTATIONS COMPARING
SAMPLE SOURCE AND SAMPLE INTERFACE

	$\lvert t \rvert$	$t_{(n-1),.05}$	$t_{(n-1),.01}$	Conclusion
TOC-Secondary	.882	2.179	3.055	.05 no difference .01 no difference
SOC-Secondary	1.014	2.179	3.055	.05 no difference .01 no difference
o/PO_4-Secondary	3.117	2.069	2.807	.05 significant diff. .01 significant diff.
NH_3-Secondary	1.399	2.145	2.977	.05 no difference .01 no difference
HP-Secondary	2.295	2.110	2.898	.05 significant diff. .01 no difference
TOC-Primary	1.181	2.179	3.055	.05 no difference .01 no difference
SOC-Primary	.809	2.179	3.055	.05 no difference .01 no difference
o/PO_4-Primary	1.847	2.093	2.861	.05 no difference .01 no difference
NH_3-Primary	2.615	2.131	2.947	.05 significant diff. .01 no difference
HP-Primary	6.099	2.120	2.921	.05 significant diff. .01 significant diff.
TOC-Raw	4.744	2.179	3.055	.05 significant diff. .01 significant diff.
SOC-Raw	.737	2.262	3.250	.05 no difference .01 no difference
o/PO_4-Raw	2.031	2.093	2.861	.05 no difference .01 no difference
NH_3-Raw	.378	2.145	2.977	.05 no difference .01 no difference
HP-Raw	.031	2.120	2.921	.05 no difference .01 no difference
TOC-Mixed Liquor	1.065	2.160	3.012	.05 no difference .01 no difference
TOC-Return Sludge	1.147	2.179	3.055	.05 no difference .01 no difference

APPENDIX B

OPERATION AND MAINTENANCE

The Sampling Assembly consists of two main sub-assemblies: the exhaust manifold and the sample manifold. These two manifolds are connected together by means of two-way motor-driven ball valves. These valves are "True Union" ball valves which provide for assembly and disassembly without additional pipe unions. Each pair of ball valves is operated as a unit to act as one three-way valve; when one is open, the other is closed. They are numbered in the following manner (note that the "A" position of any two-valve pair always results in a sample entering the sample manifold, while the "B" position always diverts that sample to the exhaust manifold):

V1(A) permits secondary effluent to enter sampling manifold

V1(B) permits secondary effluent to enter exhaust manifold

V2(A) permits primary effluent to enter sampling manifold

V2(B) permits primary effluent to enter exhaust manifold

V3(A) permits raw influent to enter sampling manifold

V3(B) permits raw influent to enter exhaust manifold

V4(A) permits mixed liquor to enter sampling manifold

V4(B) permits mixed liquor to enter exhaust manifold

V5(A) permits return activated sludge to enter sampling manifold

V5(B) permits return activated sludge to enter exhaust manifold

V6(A) permits primary sludge to enter sampling manifold

V6(B) permits primary sludge to enter exhaust manifold

V8(A) prevents sample from going to the Pretreatment Assembly

V8(B) allows flush water to be supplied to the Pretreatment Assy. while streams 4, 5, and 6 are being monitored.

V7(A) allows flush water to be supplied to the sample manifold and homogenizer plumbing following the sampling of stream 6.

The purpose of valve pairs V1 through V6 is to introduce dynamic samples, one at a time, to the sample manifold through "valve A". In this way, all sample-supply pumps run continuously to avoid settling of solids in the transfer lines.

Valve 7 is used to introduce tap water to the homogenizer plumbing; this simultaneously flushes the plumbing, homogenizer and TOC-analyzer input lines. In the manual mode, any one of these sample streams can be introduced to the sample manifold by depressing the push button associated with the desired sample stream. When it is desired to select another stream, the "All to Drain" button (located in lower right quadrant of the control panel) is pushed, then this is followed by depressing the button associated with the desired alternate stream. However, if the stream desired is the next stream in the programmed sequence only the button associated with that sample should be pushed. The circuitry permits forward sequencing, but requires a reset ("All to Drain") to go backwards in the sequence. Note: when the sequence is performed manually, the buttons must be held until all valve-drive motors have completed their cycles (approximately 2-4 seconds).

Valve-pair V8 cannot be manually actuated from the front panel. It operates so that sample streams 1, 2 or 3 (when selected) will be furnished to the Pretreatment Unit through Valve 8A. When sample streams 4, 5 or 6 are selected, Valve 8A closes and tap water is introduced through Valve 8B to the Pretreatment Unit and the colorimeters.

Valve-pair V9 is not found on the manifold, but is located in the TOC analyzer. Its purpose is to furnish to the TOC analyzer one of two samples: a homogenized sample to monitor TOC, or a filtered sample from the Pretreatment Unit to monitor SOC. In the installation at Cranston, ball valves were not used for V9. Two peristaltic pumps were installed with a common output connection. Pump "B" is energized to sample for TOC and it pumps the sample from the homogenizer. Pump "A" is energized to sample for SOC and it pumps the sample from the pretreatment output. The pump not energized acts as a closed valve and prevents mixing of the two samples.

This was designed to be a function of the TOC analyzer because of the impracticability of switching small streams with ball valves, and the relative ease of doing it with a pump in the TOC analyzer. The function, V9, cannot be selected or controlled from the front panel. Any time a new sample is selected, V9 will operate in the "B" mode which furnishes homogenizer output. Only when the system is in the automatic mode and has run through a timing cycle on samples 1, 2 or 3 will the SOC mode be selected for the next cycle on the same sample. If SOC mode is not desired, then the TOC unit's first input pump should be energized from its normal supply. Placing the wired "Dummy Plug" (Figure B.1) in J9 on the back of the Control Panel will allow the system to skip the SOC cycle completely.

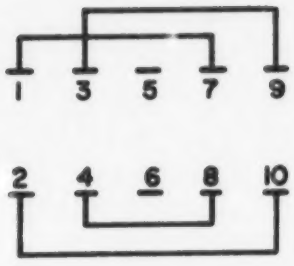


Figure B.1 Dummy Plug Wiring to Skip SOC Mode (Numbers shown are the pin numbers of the dummy plug actually used).

In automatic operation the system will progress through the sample streams in increasing numerical order starting with the one selected by depressing a pushbutton. After stream #7 (flush water) the system will revert back to stream #1. The time duration of each sampling cycle is controlled by the setting of the left timer (facing the unit). Figure B.2 shows the timing diagram for the system, and Table B.1 shows the operational sequence when a stream is selected.

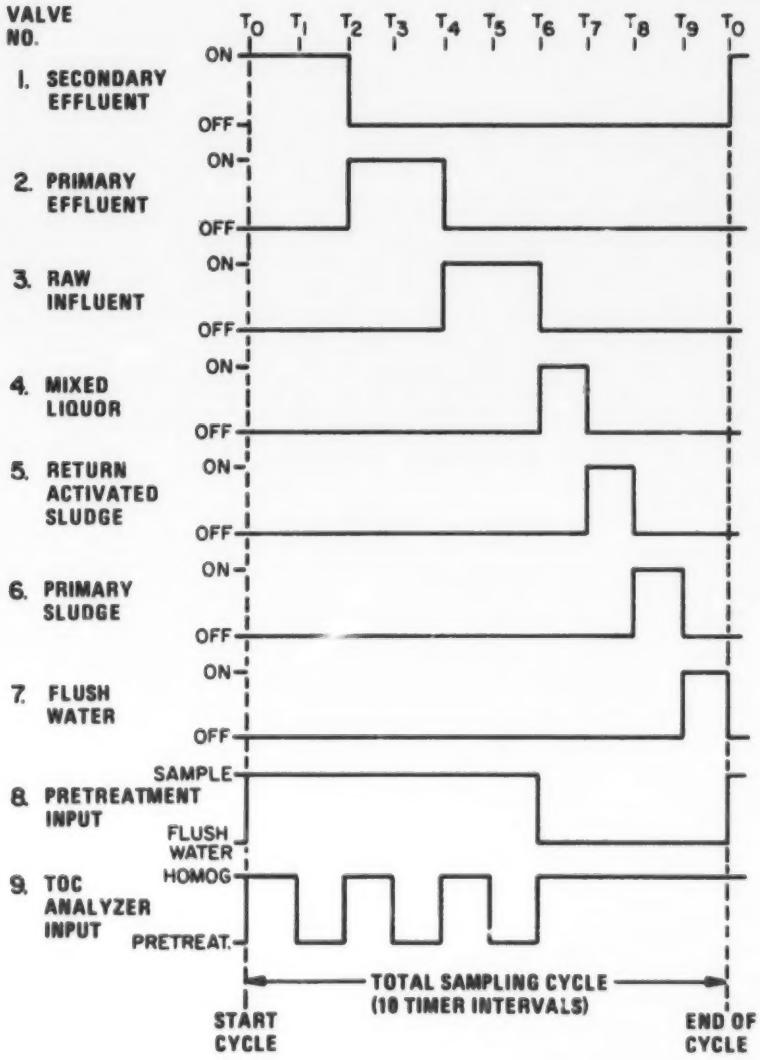


Figure B.2 Timing Diagram

TABLE B.1. TABLE OF OPERATION SEQUENCE

Time reference	Stream	Relays energized	Relays deenergized	Valves opened	Valves closed	Action accomplished
T_0	Secondary effluent	K1A, K8	Remainder	V1A, V8A, all other "B" valves	V1B, V8B, all other "A" valves	Sec. effl. to sample manifold, TOC, o-PO_4, NH_3-N, hyd. PO_4, monitored
T_1	Secondary effluent	K1A, K1B, K8, K9	Remainder	V1B, V8A, V9A, all other "B" valves	V1B, V8B, V9B, all other "A" valves	Sec. effl. to sample manifold, SOC, o-PO_4, NH_3-N, hyd. PO_4, monitored
T_2	Primary effluent	K2A, K8	Remainder	V2A, V8A, all other "B" valves	V2B, V8B, all other "A" valves	Prim. effl. to sample manifold, TOC, o-PO_4, NH_3-N, hyd. PO_4, monitored
T_3	Primary effluent	K2A, K2B, K8, K9	Remainder	V2A, V8A, V9A, all other "B" valves	V2B, V8B, V9B, all other "A" valves	Prim. effl. to sample manifold, SOC, o-PO_4, NH_3-N, hyd. PO_4, monitored
T_4	Raw influent	K3A, K8	Remainder	V3A, V8A, all other "B" valves	V3A, V8B, all other "A" valves	Raw infl. to sample manifold, TOC, o-PO_4, NH_3-N, hyd. PO_4, monitored
T_5	Raw influent	K3A, K3B, K8 K9	Remainder	V3A, V8A, V9A, all other "B" valves	V3B, V8B, V9B, all other "A" valves	Raw infl. to sample manifold, SOC, o-PO_4, NH_3-N, hyd. PO_4, monitored
T_6	Mixed liquor	K4A, K4B	K8, remainder	V4A, V8B, V9B, all other "B" valves	V4B, V8A, V9A, all other "A" valves	Flush water to P/T and analyzers, TOC monitored
T_7	Return activated sludge	K5A, K5B	K8, remainder	V5A, V8B, V9B, all other "B" valves	V5B, V8A, V9A, all other "A" valves	Flush water to P/T and analyzers, TOC monitored
T_8	Primary sludge	K6A, K6B	K8, remainder	V6A, V8B, V9B, all other "B" valves	V6B, V8A, V9A, all other "A" valves	Flush water to P/T and analyzers, TOC monitored.
T_9	Flush water	K7	Remainder	V7, all "B" valves	All "A" valves	All streams to drain, flush water to entire system

Theory of Operation

Each valve pair is controlled by the two double-throw contacts of its associated relay; i.e., valve-pair V1 ("A" and "B") is plugged into J1 where it will be controlled by K1A, etc. 115 volts AC is furnished through the de-energized relay contacts to close V1A and open V1B. When the relay is energized, 115VAC is furnished to open V1A and close V1B. When the valves are operating normally, one valve of a pair will always be open and the other closed.

When the unit is first turned on, all sequence relays are deenergized. The unit's operator can depress any one pushbutton, S1 thru S7, to energize its associated relay. (Note: S1 is associated with valve-pair V1 ("A" and "B"), J1, and K1, etc.) This opens the associated Valve A (closing Valve B) and permits that sample stream to flow to the sample manifold.

Jacks J1 thru J9 are wired so that the "A" Valves are controlled through the even-numbered contacts (reference schematic shown in Figure B.3 for a typical valve pair). Each valve is powered with a 115V motor by means of a cam-operated double-throw micro-switch. The voltage which drives the motor is returned to the panel through the activated micro-switch when the valve is in its selected position. The return voltage lights an indicator lamp that shows the status of the valve (green light indicates valve open, and red light indicates valve closed). For valve-pairs V1 through V7, the return voltages fed back from the "A" valve are used to control the relay logic for the automatic sequential operation.

On the ladder diagram (Figure B.4) find K11A, K11B, K11C, K12, and K14. Observe that K11A, K11B and K11C operate together as one relay of eleven contacts. When K11 is energized, its normally open (N.O.) contacts connect the coil of each relay (K1 thru K7) to the green-light circuit of the "A" valve that precedes it (K7 to K6, K6 to K5, etc.). Relay K11 is energized when the timer K12 completes its time cycle. K12 (N.O.) contacts close, energizing K11. K11 contacts 9 to 5 close, energizing K14. K14 contacts 1 to 4 open, resetting timer K12 and deenergizing K11 and K14. K14 is a delay-on-release relay; this delay is necessary to allow K12 time to reset. Each time K11 is operated, it applies 115V to the coil of the next relay (K1 through K7) in the sequence. Actuating any relay from K1 through K7 causes its associated valves to change condition: "A" valves open and "B" valves close. As valve "A" starts to open, its microswitch S2 changes condition, removing the holding voltage from the immediately preceding relay in the sequence. Deenergizing that relay causes its valves to assume the condition of valve "A" closed - valve "B" open.

The holding circuits of each relay (K1 thru K7) are wired from the red light of the next valve in the sequence through normally closed (N.C.) contacts of K21A and K21B. When depressed, switch S10 ("All to Drain"), energizes K21, opening the holding circuits of all sequence relays and deenergizing any energized relays. Energizing K21 also resets the K12 timer.

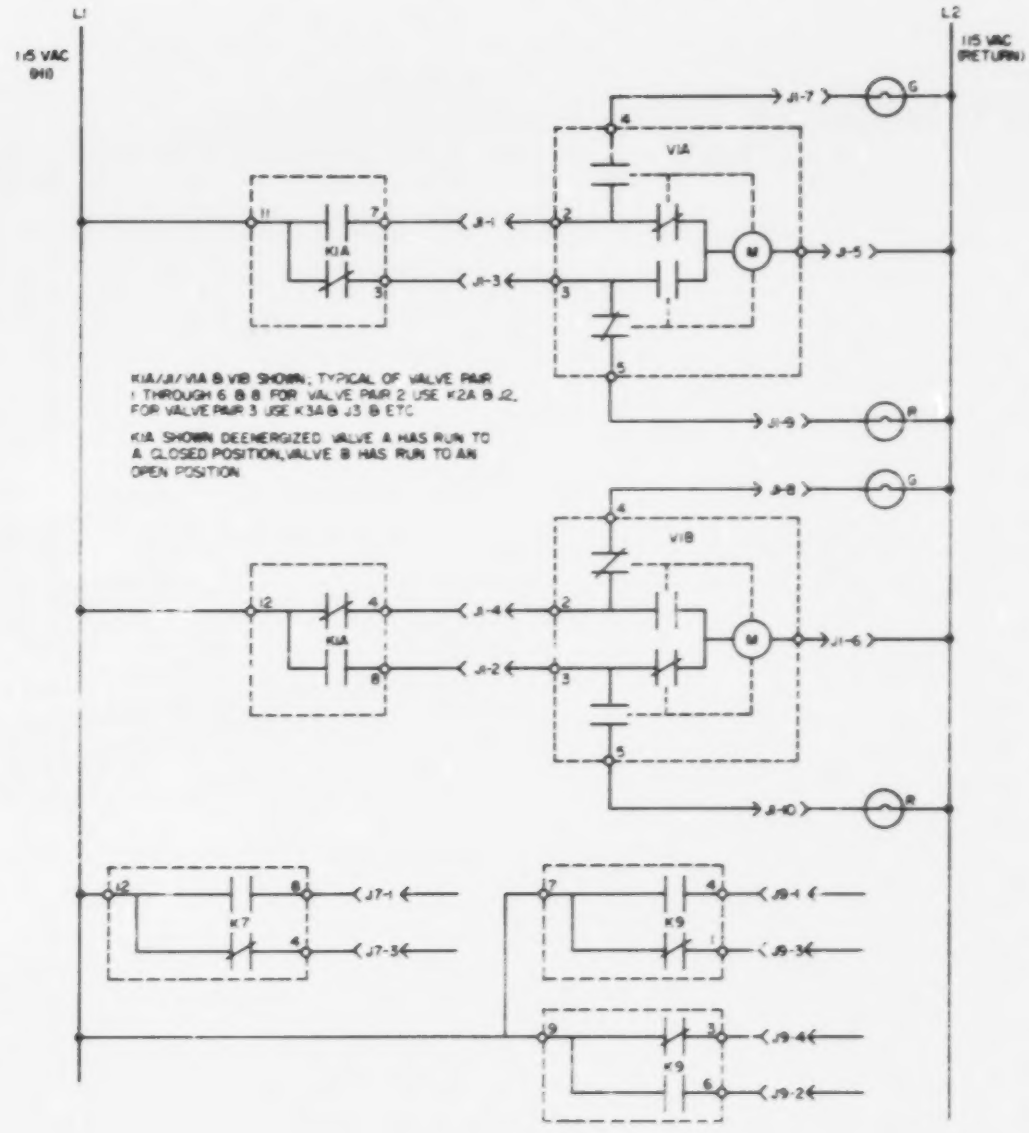
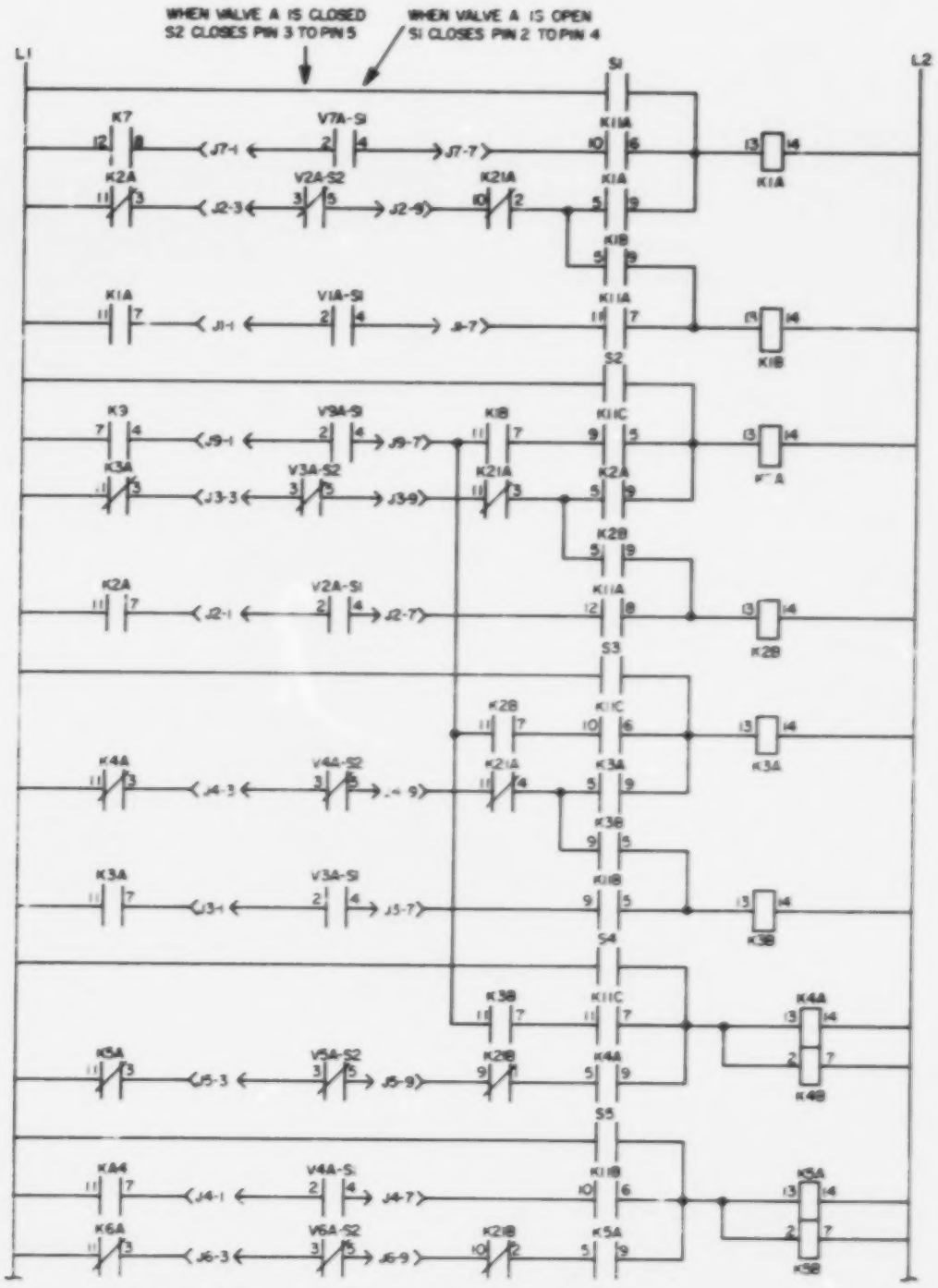


Figure B.3 Typical Valve Pairs



SWITCHES OF "A" VALVES ARE SHOWN WITH SYSTEM IN "ALL TO DRAIN" MODE, i.e. ALL "A" VALVES ARE CLOSED ("B" VALVES OPEN)

Figure B.4 Ladder Wiring Diagram (Sheet 1 of 2)

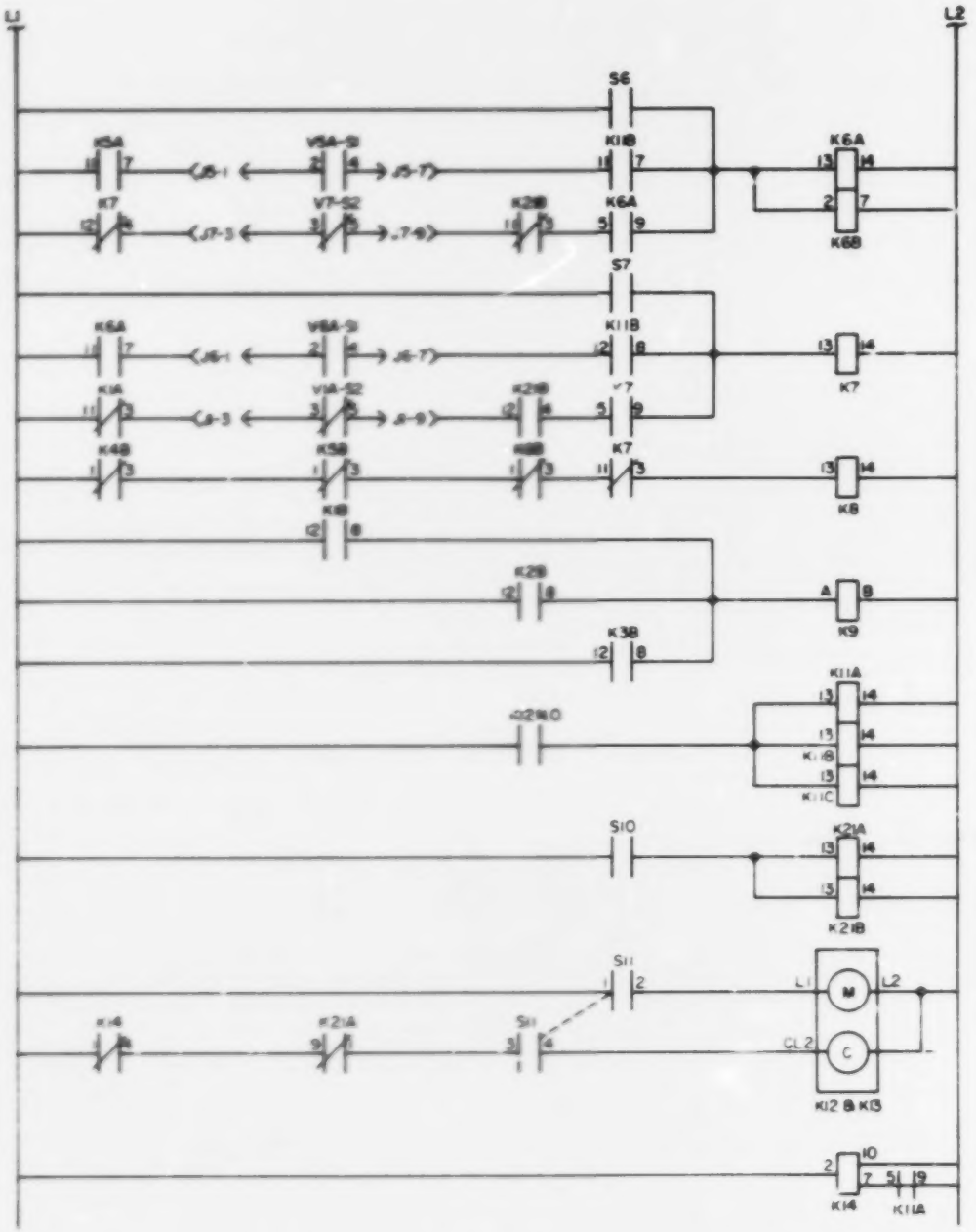


Figure B.4 Ladder Wiring Diagram (Sheet 2 of 2)

The selection of TOC/SOC by valve pairing is achieved by a modification of the basic logic of K1, K2, K3, and K4. K1A, K2A, and K3A control valve pairs V1, V2 and V3 respectively; K1B, K2B and K3B control V9 through K9. If K9 is deenergized (i.e., if V9 is functioning in the TOC mode), and if K1A or K2A or K3A is suddenly energized, the actuation of K11 causes the associated K1B or K2B or K3B to energize concurrently. Energizing K1B, K2B or K3B causes K9 to energize (through N.O. contacts 12 to 8), thus actuating V9 to the SOC mode. When K9 is energized by energizing a valve-pair (V1A-V1B, V2A-V2B, or V3A-V3B), the immediately preceding actuation of K11 causes the "A" relay of the next valve pair to energize. The sequence is as follows: K1A, K1A & K1B, K2A, K2A & K2B, K3A, K3A & K3B, K4A & K4B, K5A & K5B, K6A & K6B, K7, then back to K1A, etc. (K4A & K4B operate together as one 5-contact relay as do K5A & K5B and K5A & K6B.) If the dummy plug shown in Figure B.1 is inserted into J9 (instead of a valve pair), the voltage from J9 (pin 7) is returned instantaneously to K1B or K2B or K3B contacts 11 to 7; this energizes the next "A" relay in sequence, causing that valve pair to actuate. The sequence then is K1, K2, K3, K4, K5, K6, K7, then back to K1, etc.

K8 is energized when K4, K5, K6, & K7 are deenergized. Operating any relay K4 through K7 opens a series-arranged contact pair which deenergizes K8. When K8 is deenergized, it operates valve-pair V8 to allow flush water to flow to the pretreatment unit.

J10, J11, and J16 are trouble-shooting aids, and are hard-wired so that any valve pair (when plugged into) will do the following:

J10 - opens valve A, closes valve B

J11 - opens valve B, closes valve A

J16 - closes both valves

The voltages from the divider network (1V. to 7V.) are made available at J13-3 (Hi) & J13-1 ("0"V) to give remote indication of the program status. 1 volt indicates that the TOC for sample 1 is being monitored, 1.5V indicates that the SOC for sample 1 is being monitored, 2V indicates sample 2 TOC monitoring, etc.

The contacts of timer K13 actuate K15 and K16 to operate auxiliary equipment (i.e., a data acquisition system and a paper-tape-punch recorder). For the period of time that K13 (N.O. contact) is closed (before K12 completes its time cycle), 115V AC is furnished to J14 to operate the tape punch, and the circuit from J13 (pin 23) to J13 (pin 27) allows the data acquisition system to print data. K16 is a delay-on-energized relay. When K15 and K16 are energized, the circuit from J13 (pin 10) to J13 (pin 16) closes for 1 second (delay of K16), and the circuit from J13 (pin 13) to J13 (pin 19) opens for 1 second; this operates the "All Channel Buzz" of the tape punch, a solenoid protection device peculiar to this particular punch mechanism. K13 is reset along with K12 when K12 "times out" and operates K11, K14.

APPENDIX C

DESIGN SPECIFICATION GUIDELINES

I. GENERAL

A. This specification applies to the design of an on-line hardware system which will automatically sample, transfer and condition all types of wastewater-treatment process streams for automatic analysis without the occurrence of unacceptable chemical change in the samples prior to their analysis.

B. Application

1. Municipal wastewater-treatment plants

C. The sampling system shall consist of a series of pumps and associated piping at appropriate locations within a wastewater-treatment plant. These pumps shall supply their various samples to a centrally located sampling assembly which has the capability to select any one of the streams and condition it sufficiently so that the processed sample is adaptable to automatic on-line TOC and colorimetric analyzers. It shall have an interval flush cycle which can flush the total system after the completion of a total sampling cycle. The sampling system shall be controlled by means of a control panel which can be operated either manually or automatically.

D. To minimize transfer-line contamination, dilution pumps shall be utilized when the streams being sampled have suspended solids loadings of 1000 mg/l or greater.

II. TECHNIQUE

Each sample shall be supplied continuously to pairs of two-way valves which operate in tandem so as to simulate a three-way valve. The valve pairs shall be connected by means of union-type plumbing fittings to a sampling assembly which shall consist of an exhaust manifold and a sampling manifold. These valve pairings shall permit each sample to flow continuously, either to the sampling manifold or to the exhaust manifold. Once the sample stream reaches the sample manifold, it shall be valved to a Pretreatment Assembly (for removal of all particulate matter in preparation for colorimetric analysis) or to a homogenizer (in preparation for TOC analysis). The sampling of all process streams to be analyzed shall be a sequential operation. When the sampling

sequence has been completely traversed, the sampling assembly shall be automatically flushed with tap water prior to the initiation of another sampling sequence.

III. OBJECTIVES

The system's objectives shall be:

A. To provide for multiple stream monitoring within a wastewater-treatment plant without altering any sample's initial chemical composition.

B. To provide control signals to allow process automation.

IV. GENERAL PERFORMANCE CONSIDERATIONS

A. To handle the liquid streams within a wastewater-treatment plant (raw influent, primary effluent, and secondary effluent), centrifugal grinder pumps shall be used. These pumps shall be capable of reducing occasional large particles of suspended solids to a size of 1/4 inch (6.35 mm) which is small enough to allow an in-line homogenizer to function continuously. However, when the stream contains a large amount of fibrous material (specifically raw influent), a screen shall be utilized to prevent entrance of these fibers into the pump.

B. To handle streams having higher solids loading (mixed liquor, return activated sludge and primary sludge), a dilution pump arrangement shall be used. The sample shall be diluted at the origin to minimize solids loading within the transfer lines. Dilution shall be accomplished by utilizing a duplex pump driven by a common drive; this maintains a constant dilution ratio, even though rotor speed may vary. Each side of the pump shall have an adjustable stroke-setting to vary flowrates for desired dilution ratios. The total flow and the dilution ratios required will determine the size of the check valves. The pump shall be driven by a standard, constant speed, AC-drive motor or a suitable speed-controlled motor. The latter configuration will allow for varying total flow once a dilution ratio is established.

C. The in-line homogenizer shall utilize an abrasive rotor-stator combination to reduce particle size. The homogenizer must be able to reduce all types of particulate matter (i.e., plastics, paper fibers, and woodchips), as well as sewage, to a finally divided size on a continuous basis. Rotor clearance shall be adjustable by altering the gap between the rotor and stator to achieve a wide range of particle sizes.

D. The Pretreatment Unit shall be a packaged filtration system which provides continuous flow of representative samples for up to six on-line, water quality, monitoring instruments, while removing virtually all solid particles above 10 micrometers in size.

V. ELECTRICAL SPECIFICATIONS

A. Input Power

The central location which contains the sampling assembly and conditioning equipment shall have provision for 100-ampere, 3-phase, 230-volts, 60-HZ, AC power. The sampling system requires 50 amperes; the additional power is required for automatic analyzers.

B. Output Signals

The control panel shall have a voltage divider network serving as an indicator of which sample is being monitored in the following manner:

Indicator Voltage	Sample Stream	Parameter Monitored
1.0	Secondary effluent	Colorimetric analysis & TOC
1.5	Secondary effluent	Colorimetric analysis & SOC
2.0	Primary effluent	Colorimetric analysis & TOC
2.5	Primary effluent	Colorimetric analysis & SOC
3.0	Raw influent	Colorimetric analysis & TOC
3.5	Raw influent	Colorimetric analysis & SOC
4.0	Mixed Liquor	TOC
5.0	Return activated sludge	TOC
6.0	Primary sludge	TOC
7.0	Flush water	Complete System Flush

VI. MECHANICAL SPECIFICATIONS

A. The sample assembly, along with the control panel and homogenizer, shall not exceed 4 ft. (1.22m) width, 2-1/2 ft. (.76m) depth and 6 ft. (1.83m) height.

B. Flush-water requirements shall not exceed 5 gal/min (18.92 1/min) at 20 psi (137.9 kN/m^2) (Note: this water is not used on a continuous basis but must always be available.)

C. The sampling manifold shall be firmly mounted to the floor.

D. Positioning of automatic analyzers is very important. Automatic analyzers shall be located as close as possible to the source of the conditioned sample. Where this is not practical, analyzer input velocities shall be investigated and the associated plumbing shall be adjusted to minimize line contamination. (Minimum velocity shall be no less than 1 ft/sec. [.30m/sec.].)

VII. SAMPLE REQUIREMENTS

A. The dilution pumps must not be operated with positive input pressure. Therefore, the high-solids streams shall have a reservoir-type feed so that the pumps may draw the required sample. The reservoir must be continually replenished so that a representative (up-to-date) sample is always available.

VIII. ADDITIONAL SERVICES REQUIRED

A. Additional services are dependent upon the requirements of the automatic analyzers selected; i.e., reagents, bottled gas, etc.

IX. CONTROL AND INDICATORS

A. The control panel shall be graphically representative of the flow diagram. Red (no flow) and green (flow) indicator lights shall be incorporated to display the sampling status.

B. The system shall have two modes: automatic and manual

1. The automatic mode shall be controlled by a timer located on the front panel. Cycle time shall be manually selectable for times up to 1 hour.

C. A second timer shall be incorporated to start up auxiliary equipment (e.g., data-acquisition system) at any intermediate point within the cycle period.

X. ENVIRONMENTAL

A. Ambient Temperature:
34°F (1 °C) to 104°F (40°C)

B. Humidity:
0-95%, non-condensing

C. The grinder pumps shall be submersible pumps. The dilution pumps shall withstand adverse weather conditions.

NOTE: If the temperature goes below freezing, adequate flow must be maintained to prevent freezing within the lines.

D. The sampling system shall be contained within a shelter which is environmentally controlled (heated and air-conditioned).

XI. SAFETY PROVISIONS

A. In the event of a leak in a sample line within the shelter, all sample flow shall be directed to drain by pushing the "all to drain" button on the control panel.

B. Each pump shall have its own, independent, overload circuit located within the shelter.

APPENDIX D

LIST OF EQUIPMENT

Item	Manufacturer	Part #	Qty.	Estimated Costs (1976 dollars) Unit	Total
1) Pump, Grinder Control Box	Hydr-O-Matic Pump Co.	SPG-150A2	3	875	2,625
2) Pump Dilution with Control Box	BIF	1722-92-9517	2	690	1,380
3) Pump, Dilution with Control Box	BIF/Seco	1722-92-9510	1	---	1,020
4) Mixer, Static	Kenics	37-08-136	3	145	435
5) Homogenizer	Raytheon	2650	1	---	1,350
6) Hose, 1"	B. F. Goodrich	BFG300	670 ft.	.94/ft.	630
7) Hose, 3/8"	B. F. Goodrich	BFG300	1,000 ft.	.36/ft.	360
8) Assembly, Control Panel and Rack	Raytheon	Special	1	---	1,320
9) Assembly, Grinder Pump Cable	Raytheon	Special	1,000 ft.	1.54/ft.	1,540
10) Assembly, Dilution Pump Cable	Raytheon	Special	1,000 ft.	.66/ft.	660
11) Assembly, Connector Panel	Raytheon	Special	1	---	320
12) Pump, Peristaltic	Randolph	Special	1	---	126
13) Assembly, Sampling and Exhaust	Raytheon	Special	1	---	4,598
14) Cabinet, Reagent	Raytheon	2590	2	650	1,300
15) Pretreatment Unit	Raytheon	2550	1	---	3,950
Total Equipment Cost					$21,614

APPENDIX D - LIST OF EQUIPMENT (Cont'd)

AUXILIARY EQUIPMENT

Name	Manufacturer	Part #	Qty
TOC Analyzer	Raytheon	2600	1
Orthophosphate Analyzer	Raytheon		1
Monitor IV	Technicon		1
Data Acquisition System	Esterline Angus	D2020	1
TOC Analyzer	Beckman	915	1
Microscope	Bausch & Lomb	XL1	1
Spectrophotometer	Bausch & Lomb		1

GLOSSARY OF TERMS AND ABBREVIATIONS

Contamination	-	Settled particles in transfer lines.
Deadending	-	Allowing a stream to stop flowing.
Grab Samples	-	Samples taken by hand.
Hyd. PO_4	-	Hydrolyzable phosphate expressed as phosphate.
Interface	-	That point at which all sample transporting and conditioning have been performed.
NH_3-N	-	Ammonia expressed as nitrogen.
o-PO_4	-	Orthophosphate expressed as phosphate.
P/T	-	Pretreatment Assembly (Filtration Unit).
SOC	-	Soluble organic carbon.
Source	-	That point (usually a unit process) at which sampling originates.
Sparging	-	Process by which inorganic carbon is removed from a solution by agitation with a CO_2-free gas.
Time-Lag	-	Time during which valid data cannot be obtained.
TOC	-	Total organic carbon.